DEPARTMENT OF THE AIR FORCE
HEADQUARTERS 49TH FIGHTER WING (ACC)
HOLLOMAN AIR FORCE BASE, NEW MEXICO

22 MAR 1995

MEMORANDUM FOR NEW MEXICO ENVIRONMENT DEPARTMENT
Groundwater Protection & Remediation Bureau
Attn: David Morgan
1190 St Francis Dr
Santa Fe, NM 87502

1995
RECEIVED
HAZARDOUS WASTE
PROGRAM

FROM: 49 CES/CEV
550 Tabosa Avenue
Holloman AFB, NM 88330-8458

SUBJECT: Review of Bioventing Initiative Work Plan

1. Attached please find work plans pertaining to Installation Restoration Program (IRP) Sites FT-31, the Fire Training Area, and SD-47, the POL Washrack. These work plans require your review prior to initiation of field work, which is scheduled to begin in the next 2-3 weeks. Therefore, an expedient review is requested in order to maintain the accelerated restoration schedule established last year.

2. If you have any further questions regarding the enclosed work plans, please contact Warren Neff at (505) 475-5395.

Howard E. Moffitt
HOWARD E. MOFFITT
Deputy Base Civil Engineer

Attachment:
Bioventing Initiative Work Plan Vols 1-3, March 1995

cc: w/Atch

Mr Steve Pullen
New Mexico Environment Department
Hazardous and Radioactive Materials Bureau
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US Environmental Protection Agency
Hazardous Waste Management Division
1445 Ross Ave
Dallas, TX 75202-2733

RCRA Facility Stabilization Initiative

BACKGROUND: **The Resource Conservation and Recovery Act (RCRA) Facility Stabilization Initiative is a result of the Environmental Protection Agency's (EPA's) comprehensive evaluation of the RCRA Hazardous Waste Regulatory Program. The findings and recommendations of this evaluation led to the development of the RCRA Implementation Study (RIS), which reported on issues germane to RCRA, including the RCRA Corrective Action Program. Corrective Action is EPA's primary mechanism for addressing releases of hazardous wastes and hazardous constituents from RCRA treatment, storage, and disposal facilities. EPA issued a proposed rule on RCRA Corrective Action on July 27, 1990 (55 FR 30798 et seq.); however, the only portion of this rule that is final is the regulations concerning corrective action management units (CAMUs) and temporary units (TUs) published on February 16, 1993 (58 FR 3658 et seq.).**

One of the recommendations identified by the RIS for improving the Corrective Action Program involved the implementation of "stabilization" efforts at facilities having actual or imminent releases. As a further recommendation, the RIS proposed that a prioritization system be devised for identifying those facilities most in need of an interim measure, in order to provide greater near-term environmental benefits where environmental media and receptors are significantly at risk. These recommendations provided the impetus for the Stabilization Initiative, which was introduced to the EPA Regional offices in the fall of 1991.

STATUTE: **The Stabilization Initiative is not statutorily driven, but is being implemented under RCRA.**

REGULATIONS: **No specific regulations apply; however, the stabilization philosophy is being applied in proposed 40 CFR 264, Subpart S (55 FR 30798 et seq.; July 27, 1990).**

REFERENCE:

1. **"Managing the Corrective Action Program for Environmental Results: The RCRA Facility Stabilization Effort," U.S. Environmental Protection Agency, OSWER Memorandum to Region I-X Waste Management Division Directors, October 25, 1991.**
2. **"The RCRA Implementation Study," U.S. Environmental Protection Agency, EPA/530-SW-90-069, July 1990.**
3. **"Region III Approach to Stabilization," U.S. Environmental Protection Agency, OSWER Memorandum to Director for RCRA Programs for Region III, May 4, 1992.**
4. **"RCRA Corrective Action Program Guide - Interim Guidance," U.S. Department of Energy, Office of Environmental Guidance, RCRA/CERCLA Division, Guidance Manual, DOE/EH-0323, May 1993.**
5. **"RCRA Corrective Action Interim Measures Under the Proposed Subpart S Rule," U.S. Department of Energy, Office of Environmental Guidance, RCRA/CERCLA Division, RCRA Information Brief, EH-231-024/0793, (July 1993).**
6. **"The National Corrective Action Prioritization System," U.S. Environmental Protection Agency, Fact Sheet, EPA 530-F-92-027, January 1993.**
7. **"RCRA Corrective Action Stabilization Technologies," U.S. Environmental Protection Agency, Proceedings, EPA/625/R-92/014, October 1992.**
8. **"Stabilization Technologies for RCRA Corrective Actions Handbook," U.S. Environmental Protection Agency, EPA/625/6-91/026, August 1991.**

What is the RCRA Facility Stabilization Initiative?

The RCRA Facility Stabilization Initiative was developed as a means of implementing the Corrective Action Program's management goals recommended by the RIS for "stabilizing" actual or imminent releases from solid waste management units (SWMUs) that threaten human health and the environment. The overall goal of stabilization is to, as situations warrant, control or abate threats to human health and/or the environment from releases at RCRA facilities, and/or to prevent or minimize the further spread of contamination while long-term remedies are pursued.

The Stabilization Initiative is a management philosophy and should not be confused with stabilization technologies (e.g. solidification, vitrification, and other immobilizing techniques). While such technologies may effectively stabilize wastes, the focus of the Stabilization Initiative is much broader. The traditionally slow pace of implementing effective long-term remedies for releases from SWMUs has prompted EPA to consider accelerated corrective measures to reduce the risks posed by a release. Technologies to reduce risk may include any, or a combination of, treatment, containment, or exposure controls. The Stabilization Initiative measures are intended to address releases to all environmental media (i.e., air, soil, surface water, and ground water). Implementation of Stabilization Initiative activities (i.e., through the use of corrective action interim measures) will be dependent upon varying site-specific factors, such as the technical complexity of the remediation, quantities and types of waste to be addressed, media-specific characteristics, and exposure threats to various environmental receptors.

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EPA's Stabilization Initiative guidance (Reference 1) identifies three conditions under which stabilization may be appropriate for a facility. These conditions include:

- ❒ Releases at the facility that pose actual or imminent exposure threats to humans or ecosystems at levels of concern;
- ❒ Releases that, if not addressed expeditiously, will result in further significant contamination of environmental media in the near to mid term (e.g., 5-10 years), or;
- ❒ Site characteristics that suggest the site may be amenable to measures designed to control or abate imminent threats or prevent or minimize the further spread of contamination.

Generally, a determination as to whether stabilization activities will be appropriate is based upon information identified in a RCRA Facility Assessment (RFA) report. Further refinement and selection of an appropriate stabilization activity normally occur during the second phase of the corrective action process, the RCRA Facility Investigation (RFI), when specific physical and technical data concerning a release can be evaluated and considered.

May proposed RCRA Subpart S Interim Measures be used under the Stabilization Initiative?

The overall objectives of the Stabilization Initiative and corrective action interim measures are basically the same; that is, to mitigate near-term threats to human health and the environment by preventing or minimizing further spread of contamination until a final remedy may be implemented. As such, interim measures are one of the types of tools used under the Stabilization Initiative.

Conditional remedies and voluntary actions may also be used under the Stabilization Initiative. Conditional remedies are intended to phase in remedies over a period of time and, therefore, may include activities intended to control the future migration of wastes onsite and to expedite cleanup of releases that have migrated beyond the facility boundary. Voluntary corrective actions may be conducted by facility owners/ operators who wish to initiate stabilization activities rather than wait for the EPA to begin actively pursuing corrective action at the facility.

The Stabilization Initiative is intended to work in harmony with the overall RCRA Corrective Action Program by prioritizing corrective action needs and by taking stabilization actions as appropriate, based on prioritization and other factors. The key to the prioritization effort is the National Corrective Action Prioritization System (NCAPS). NCAPS is based upon information provided from the Corrective Action Stabilization Questionnaire, which evaluates data collected from facility RFAs. NCAPS will allow EPA Regions to establish a means of objectively determining which facilities (and specific SWMUs) need the most immediate attention. This "worst case" approach allows EPA to direct program resources for achieving stabilization goals more efficiently, to concentrate upon releases posing the most significant threats, and to more clearly assess the level of oversight needed at facilities that have lower priority.

How is the Stabilization Initiative implemented by regulatory agencies?

A stabilization measure is imposed by EPA or an authorized State and will be implemented through a six-step process:

- ❒ Assignment of a priority level for corrective action and stabilization based on the NCAPS;
- ❒ Evaluation of facility and contamination releases to determine whether they can be addressed through stabilization;
- ❒ Modification of the permit compliance schedule in a permit or enforcement order to include clauses requiring stabilization;
- ❒ Collection of data needed to select and design the stabilization measures;
- ❒ Selection and design of stabilization measures (i.e., interim measures); and
- ❒ Implementation of stabilization measures.

If the facility implements stabilization activities upon its own discretion, the process would be different and would have to be modified. For example, because the regulatory agency assigns the NCAPS priority on a program-wide basis, this step is meaningless when the facility initiates stabilization itself. By taking the initiative, the facility believes stabilization is necessary regardless of how it is prioritized under NCAPS.

How should the Stabilization Initiative be implemented at DOE facilities?

The Stabilization Initiative is initiated by EPA Regions or authorized States as part of existing facility permit requirements, enforcement orders, or compliance agreements. EPA intends to develop flexible schedules of compliance through these mechanisms that allow stabilization-focused data gathering and subsequent implementation of stabilization activities prior to completion of an RFI.

DOE is committed to complying with all environmental laws and regulations that apply to its program and operations, and generally supports all initiatives that further this commitment in an efficient and effective manner. Given DOE's evolving role and responsibilities regarding environmental issues, Environmental Restoration Program Managers may wish to undertake, where circumstances or conditions permit, actions to implement the goals of the Stabilization Initiative primarily through voluntary corrective actions that provide for public participation and regulatory authority involvement. Such actions are encouraged by EPA as a means to further expedite the overall goal of remediation.

Will the Stabilization Initiative result in new regulatory requirements?

The Stabilization Initiative is solely a management strategy and will not create a formal regulatory or administrative process. The goals of the Stabilization Initiative are being incorporated and implemented through the RCRA Corrective Action Program and are applied using interim measures.

When is the Stabilization Initiative considered complete?

The success or failure of any stabilization measure is based upon a determination of whether the interim measure(s) employed reduce the near-term hazard posed to human health and the environment and/or further contain waste migration. Another indicator of a successful stabilization action is the compatibility between the interim measure initiated and the final corrective measure selected for implementation. While an interim measure is generally intended as a stop-gap activity, it may be suitable to serve as the final remedy for corrective action. Regardless of the situation, the ultimate success of a corrective measure is based upon the sum of the actions taken to achieve the final goal. In the case of stabilization, the contribution a given action makes in the overall cleanup is the true measure of the effectiveness and success of the Stabilization Initiative.

Questions of policy or questions requiring policy decisions will not be addressed in EH-231 Information Briefs unless that policy has already been established through appropriate documentation. Please refer any questions concerning the subject matter covered in this Information Brief to Jerry Coalgate, RCRA/CERCLA Division, EH-231, (202) 586-6075.

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Headquarters, Air Combat Command
Langley Air Force Base,
Virginia

BIOVENTING INITIATIVE WORK PLAN

SITES SD-47 AND FT-31

VOLUME II - QUALITY ASSURANCE PROJECT PLAN

March 1995

49 CES/CEV
Holloman Air Force Base,
New Mexico

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Information Request
Malfunction Report

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LIST OF ACRONYMS

AA	Atomic Absorption
AFB	Air Force Base
ASTM	American Society for Testing and Materials
API	American Petroleum Institute
BFB	4-Bromo Fluorobenzene
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CCC	Calibration Check Compound
CCCS	Continuing Calibration Check Compound
CCV	Continuing Calibration Verification
CFR	Code of Federal Regulations
CLP	Contract Laboratory Program
CVAA	Cold Vapor Atomic Absorption
DDT	Dichloro-diphenyltrichloroethane
DFTPP	Decafluorotriphenylposphine
DOC	Demonstration of Capability

LIST OF ACRONYMS (Continued)

DPT	Direct Push Technology
DQCR	Daily Quality Control Report
DQO	Data Quality Objective
ELCD	Electron Conductivity Detector
EPA	United States Environmental Protection Agency
FID	Flame Ionization Detector
FOP	Field Operations Plan
GC	Gas Chromatography
GC/MS	Gas Chromatography/Mass Spectrometry
GFAA	Graphite Furnace Atomic Absorption
IC	Initial Calibration
ICPES	Inductively Coupled Plasma Emission Spectroscopy
ICV	Initial Calibration Verification
IDW	Investigation-derived Waste
IR	Infrared Spectrometry

LIST OF ACRONYMS (Continued)

LCS	Laboratory Quality Control Check Sample
MCL	Maximum Contaminant Levels
MDL	Method Detection Limit
mg/l	Milligrams per Liter
mg/kg	Milligrams per Kilogram
mg/m^3	Milligrams per Cubic Meter
MS	Matrix Spike
MSD	Matrix Spike Duplicate
MRD	Missouri River Division
NCR	Nonconformance Report
NIST	National Institute for Standards and Technology
nm	Nanometer
PCRF	Procedure Change Request Form
PID	Photo Ionization Detector
ppb	Parts per Billion

LIST OF ACRONYMS (Continued)

ppm	Parts per Million
PQL	Practical Quantitative Limit
QA	Quality Assurance
QAC	Quality Assurance Coordinator
QAPP	Quality Assurance Project Plan
QC	Quality Control
QCCS	Quality Control Check Sample
OVA	Organic Vapor Analyzer
RCRA	Resource Conservation and Recovery Act
RF	Response Factor
RL	Reporting Limit
RP	Recommended Practice
RPD	Relative Percent Difference
RSD	Relation Standard Deviation
SOP	Standard Operating Procedures

LIST OF ACRONYMS (Continued)

SPCC	System Performance Check Compound
SW	Solid Waste
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TIC	Tentatively-Identified Compound
TPH	Total Petroleum Hydrocarbon
TRPH	Total Recoverable Petroleum Hydrocarbons
ug/l	Micrograms per Liter
ug/kg	Micrograms per kilogram
USACE	U.S. Army Corps of Engineers
VOC	Volatile Organic Compounds
ZHE	Zero Headspace Extractor

1.0 INTRODUCTION

This Quality Assurance Project Plan (QAPP) has been prepared as Volume II of the Bioventing Initiative Work Plan for Sites SD-47 and FT-31 at Holloman Air Force Base (AFB), New Mexico.

The purpose of this QAPP is to ensure that data collected during these activities are of adequate quality for the purposes of determining the appropriateness of bioventing as a remedial alternative. The QAPP describes the procedures which will be used to document and report precision, accuracy and completeness of the environmental measurements to be performed.

This QAPP addresses the quality assurance elements required by the "General Chemistry Supplement to the Scope of Services", United States Army Corps of Engineers (USACE), Omaha District, December 1993.

The remainder of this document is organized in the following manner:

- Section 2.0 - Project Organization and Functional Area Responsibilities;
- Section 3.0 - Data Quality Objectives;
- Section 4.0 - Field Activities;
- Section 5.0 - Laboratory Analytical Procedures; and
- Section 6.0 - Quality Assurance Audits.

2.0 PROJECT ORGANIZATION AND FUNCTIONAL AREA RESPONSIBILITIES

The project team for the Holloman AFB bioventing initiative will be comprised of a project manager, a quality assurance coordinator (QAC), and one or more task leaders. The roles and responsibilities of these key personnel are discussed below.

2.1 Roles and Responsibilities

The contractor project manager will be responsible for organizing and directing the technical activities of the project and for reporting the results of these activities. This position will have overall responsibility, authority, and accountability for the project. The project manager will have daily interaction with the technical staff. This individual will perform the following:

- Establish technical objectives, review and modify the work plans in accordance with client directions;
- Be responsible for responding to work plan revisions;
- Be responsible for meeting all contractual requirements for the task;
- Be responsible for meeting budget and schedules;
- Ensure technical quality of reports, memoranda, and other communications through review of results;
- Maintain contact with the USACE project manager and provide information regarding all aspects of the project, including progress, problems, and recommended solutions;
- Be responsible for ensuring that required staffing levels and technical expertise are provided; and
- Be responsible for reviewing project staff performance through the program.

The QAC will be responsible for development and execution of quality assurance (QA) activities in all phases of the project, including implementation, data reduction and reporting. The responsibilities of the QAC include:

- Coordinating any external QA audit activities requested by the USACE;

- Serving as a resource to the project manager and task leaders in defining data quality goals or requirements;
- Developing a project-specific internal quality control (QC) system that is responsive to the goals of this QAPP;
- Reviewing and validating field and laboratory analytical data generated during the bioventing initiative;
- Coordinating preparation of the project QA reports that document the project specific activities designed to achieve data quality goals or requirements;
- Providing a mechanism for communication of QA problems to the project manager for implementation of corrective action; and
- Documenting QA/QC activity results for the project manager and the client.

Field task managers will be designated for all tasks related to the bioventing initiative. The responsibilities of these individuals include field activities and reporting. General responsibilities of field task managers include:

- Responsibility for ensuring that deliverables required for their specific task are delivered on schedule and within budget;
- Daily coordination of project team staff members;
- Communication with the project manager regarding technical problems, scheduling and budget;
- Coordination of daily QC activities required as part of the internal QC system;
- Ensuring compliance with all QC acceptance criteria as specified in this QAPP; and
- Communicating with the QAC and project manager regarding any quality problems that may arise.

The field task manager will be responsible for all on-site activities, including sample collection, field analysis, chain of custody and reporting. This individual will be responsible for management of the field staff. The field task manager will be responsible for completing daily quality control reports (DQCRs) (Appendix B).

2.2 Subcontractor Qualifications

The minimum qualifications of project subcontractors are summarized in the following subsections.

2.2.1 Off-Site Analytical Laboratory

GTEL Environmental Laboratory in Wichita, Kansas is the primary analytical laboratory for this project. GTEL's qualifications include current USACE validation (January 1994-June 1995). GTEL will provide Level III data packages for this project. The analytical laboratory representative will have the ultimate responsibility for all analyses performed at the analytical laboratory. The assigned laboratory representative will ensure that the work is completed as outlined in the Holloman AFB Final Specifications for the Bioventing Initiative and this QAPP.

The secondary analytical laboratory (GTEL Environmental Laboratory in Concord, California) will be utilized in overflow situations which may result at the primary laboratory. The secondary analytical laboratory representative will have ultimate responsibility for all analyses performed at the secondary analytical laboratory. This individual will also ensure that the work is completed as outlined in the Holloman AFB Final Specifications for the Bioventing Initiative and this QAPP.

2.2.2 Mobile Analytical Laboratory

Analytical Technologies, Inc. in Albuquerque will provide on-site laboratory analyses during the soil gas survey. Analytical Technologies qualifications include a current USACE validation. The on-site analyses from the soil gas survey will be used as a screening tool and will meet Level II data quality objectives. The laboratory will be responsible for performing the analyses as specified in the Holloman AFB Bioventing Initiative Work Plan (FOP) (Volume I - Field Operations Plan) and the QAPP (Volume II).

2.2.3 Geotechnical Laboratory

A geotechnical testing laboratory will provide all geotechnical testing support. The laboratory will be responsible for conducting the requested analyses in accordance with the appropriate American Society for Testing and Materials (ASTM) and American Petroleum Institute (API) standards. The equipment used during the testing process will be appropriately calibrated prior to testing project samples. The assigned geotechnical laboratory representative will ensure that the work is completed as outlined in the Holloman AFB Bioventing Initiative Work Plan (Volume I - Field Operations Plan).

2.2.4 Direct Push Technology Sampling

Geo Environmental of Golden, Colorado will use direct push technology (DPT) sampling techniques to conduct the soil gas survey. An assigned representative will be responsible for completing the work as stated in the Holloman AFB Bioventing Initiative Work Plan (Volume I - Field Operations Plan).

2.2.5 Drilling

Raba Kistner of El Paso, Texas will be subcontracted to provide all drilling services. This company is a licensed New Mexico water-well driller. An assigned drilling company representative will be responsible for completing the work as stated in the Holloman AFB Bioventing Initiative Work Plan (Volume I - Field Operations Plan).

2.2.6 Survey Activities

The location and elevation of boreholes, soil gas survey points, and monitor wells will be surveyed by a licensed surveyor. The surveyor will be registered in the State of New Mexico and will follow all survey protocols outlined in the Holloman AFB Bioventing Initiative Work Plan (Volume I - Field Operations Plan).

2.3 USACE Missouri River Division Laboratory

The USACE Missouri River Division (MRD) is responsible for providing QA services to the USACE project manager and chemist. However, for this project, no QA duplicate samples were specified in the USACE scope of service.

3.0 DATA QUALITY OBJECTIVES

To support the overall project objectives, chemical data quality objectives (DQOs) must be established. The chemical DQOs are:

- Collect samples as outlined in the final specifications for the Bioventing Initiative to assess potential releases, characterize waste materials, and provide data for closure;
- Ensure data comparability through the use of standard methods and controlled systems to collect and analyze samples;
- Provide analytical results with known and acceptable precision and accuracy;
- Provide 90% data completeness for analytical results representing each matrix-method combination; and
- The completeness objective for the project will be 95% valid data for each matrix-method combination. Minimum acceptable completeness will be 90%.

Measurement data representativeness is a function of sampling strategy and will be achieved using the procedures prescribed in this Bioventing Initiative Work Plan. Potential for sample contamination will be minimized by the use of decontamination procedures specified in the FOP (Volume I) of the Work Plan. Data comparability will be achieved using standard methods and standard units of measure as specified in the methods described in Section 5.1 and Table A-1. Analytical imprecision and bias will be controlled through the use of a QC program using prescribed QC samples and the corrective actions specified in Section 5.5 and Table A-3. Imprecision and bias in natural matrix samples will be estimated by standard QC methods such as matrix spikes and field duplicates.

A QA/QC program will be used to ensure that the analytical DQOs are met for this program. QA/QC efforts are twofold. First, they provide the mechanism for ongoing control and evaluation of measurement data quality throughout the course of the project (i.e., system capability). Second, they specify QC data to be used to define natural matrix data quality for various measurement parameters in terms of precision and accuracy. Control of measurement data quality (i.e., control of error sources that affect data quality) is possible for sample collection and analysis. However, matrix interference, or non-homogeneity, is not amenable

to control and thus imprecision or bias due to these natural sources of error must be estimated from QC samples. For this project, sample collection error will be controlled through the use of standard sample collection methods and field log books. Sample analysis error will be controlled through the use of standard analytical methods and adherence to Standard Operating Procedures (SOPs). Natural matrix error will be estimated by standard QC methods such as field and laboratory duplicates.

3.1 Analytical Capability

Efforts to control measurement error require that the analytical system be capable, in control, and appropriately sensitive for all analyses. System capability, in terms of accuracy and precision, may be documented by reporting system QC data (e.g., continuing calibration, laboratory quality control check samples [LCS], method matrix spikes [MS], and matrix spike duplicates [MSD]). System performance and sensitivity will be documented through the use of annual method detection limit studies and control charts.

MS- and MSD-analyses will be conducted on field samples. These samples will be chosen by the laboratory and processed in the manner and frequency discussed in Section 5.5.2 and 5.5.3 of this QAPP. The soil sampling plan in the FOP (Volume I, SOP A-6) account for the collection of sufficient amounts of samples for laboratory to conduct the MS and MSD analyses on any sample.

The stated objective for completeness is 95% for each matrix-method combination. Completeness is defined as the ratio of the valid data to total data collected over the course of the project. Data will be considered valid if they are adequate for their intended use and meet the precision, accuracy, and reporting limit objectives defined below.

3.1.1 Precision and Accuracy

Precision and accuracy objectives, for the various measurement parameters associated with site characterization efforts are presented in Table 3-1. Precision will be calculated from MS and MSD analyses and expressed in terms of relative percent difference (RPD). RPDs will be evaluated against precision objectives stated in Table 3-1. Percent recovery values for MS samples include components of both random error (i.e., variability from imprecision) and

systematic error (i.e., bias), and thus reflect the total analytical error for a given measurement, expressed as a percentage of the true spike value. Recovery values will be compared with accuracy objectives stated in Table 3-1. Other method controls will be followed in accordance with US Environmental Protection Agency (EPA) Solid Waste (SW)-846, and GTEL SOPs for each of the required analyses.

GTEL routinely utilizes statistically derived limits to evaluate method performance against method stated criteria. If statistically derived limits are broader than those in Table 3.1 and Appendix Table A-5, then the values in these tables will apply and control. The limits in this document are within method stated criteria. Note: That GTEL uses the published Contract Laboratory Program (CLP) limits for methods, SW8240, SW8270, and SW8080.

Accuracy and precision objectives presented in Table 3-1 may not be achievable in all cases because variability and complexity of a sample matrix cannot be controlled. The stated objectives in Table 3-1 should be achieved for 90% of the control samples (95% completeness). When the objectives are not met, documentation will be provided explaining the suspected reason for the variance. The percent recovery between true and measured concentrations of LCS may be compared with accuracy objectives in Table A-4. The basis for these estimates are, in most cases, described in the methods. The analytical laboratory will be able to document that the QA/QC procedure in each standard method, (Chapter One and Method 8000A of SW-846, Update 1, July 1992, or USACE Guidance Document ER 1110-1-263) was followed for all analytical work.

3.1.2 Method Reporting Limits

Method reporting limits (RLs) for this project are presented in Table 3-2. Actual method RLs may not reach the project limits for all analytes in all cases, particularly when sample matrix issues dictate that sample dilution must be performed. Conditions that prevent complete data capture, such as significant sample matrix difficulties or sample loss, will be addressed in a timely fashion to determine which corrective actions should be taken.

For a number of compounds, the specified RL does not reach the Resource Conservation and Recovery Act (RCRA)-required limit for the methods included in this investigation. Although known limitations exist, data will be considered usable because they are generated using

current promulgated method. In most cases, the sample-specific detection limit is lower than the RL. Natural sample RLs will also depend on dilution effects. In general, dilutions will be performed only as directed in each representative method. For target analytes on gas chromatography/mass spectrometry (GC/MS) and GC analyses, dilution will be performed if the target analyte concentrations exceed the calibration range. For nontarget analytes on GC/MS and GC analyses, dilutions will be performed when nontarget analyte response interferes with target analyte response. When samples are diluted after an initial undiluted analysis, data for target analytes with responses within the calibration range in the undiluted analysis will be collected. These values will be reported with target analytes that required diluted analyses, except in cases where RLs will not result in unusable data. If natural sample RLs exceed RCRA-required limits for any other compounds, the analytical laboratory must document what prompted the higher RLs. The maximum concentrations that were allowable on a sample-by-sample basis may not be applied to batches of samples.

QC procedures used as an ongoing control (i.e., feed-back mechanism) for the analytical system are presented in Section 5.5 and Tables A-3 through A-6 in Appendix A. Control procedures, acceptance criteria, and corrective actions are detailed for each method. Data for each control procedure will be evaluated against these acceptance criteria to prove the analytical system was in control during sample analyses and thus, the results are defensible. These tables are summaries of information from SW-846 Chapter One, Method 8000A and individual methods. As such, they are intended to be used as guides.

Table 3-1. Analytical Precision and Accuracy Objectives for Natural Matrix Spikes

Parameter	Method	Precision[a]	Accuracy[b]
Iron (Total)	SW6010A ICPES	20%	80-120%
Alkalinity	E 310.1 (Modified for soil analysis)	20%	80-120%
Total Kjeldahl Nitrogen	E 351.2 (Modified for soil analysis)	20%	80-120%
Phosphorus (Total)	E 365.4 (Modified for soil analysis)	20%	80-120%
pH (soil)	SW9045A	0.2 pH Unit	NA
Volatile Organic Compounds (BTEX)	SW8020 (Modified for BTEX) GC	See Method 8020 Table A-5	See Method 8020 Table A-5
Total Recoverable Petroleum Hydrocarbons	Modified E418.1 IR	See Method E418.1 Table A-5	See Method E418.1 Table A-5
Soil Gas BTEX and Total Petroleum Hydrocarbons	SW8020/8015 (Modified) GC/PID/FID	20%	See Method 8020/8015 Table A-5

[a] Relative percent difference for replicate analytical determinations (exclusive of sampling variability).

[b] Total error for a single measurement in a clean, laboratory-controlled matrix, including both systematic error (bias) and random error (variability from imprecision), expressed as a percentage of the measured value. Percent recovery for QCCS or continuing calibration samples will be compared to these objectives.

SW = Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods, U.S. EPA, Office of Solid Waste and Emergency Response, November 1986, Third Edition.
E = Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020.
ICPES = Inductively Coupled Plasma Emission Spectroscopy
GC = Gas Chromatography
IR = Infrared Spectrometry
PID = Photoionization Detector
FID = Flame Ionization Detector

Table 3-2. Analytical Methods, Method Reporting Limits, and Maximum Contaminant Levels

Parameter	Analysis		Reporting Limits[a]		Action Levels/Health-Based Levels		
	Technique	Method	Water (ug/l)	Soil (mg/kg)	MCL[b] (Water) (mg/l)	RCRA[c,e] (Water) (mg/l)	RCRA[c,e] (Soil) (mg/kg)
TOTAL METALS (ug/l or mg/kg)							
Iron	ICPES	SW6010A	100	10	--	--	--
VOLATILE ORGANICS (ug/l or mg/kg)							
Benzene	GC	SW8020	0.5	0.05	0.005	--	24
Ethyl benzene	GC	SW8020	1	0.1	0.7	--	8,000
Toluene	GC	SW8020	1	0.1	0.75[f]	--	16,000
Xylenes (total)	GC	SW8020	2	0.2	10[f]	--	160,000
INORGANIC ANALYSES (mg/l or mg/kg)							
Alkalinity (mg $CaCO_3$ per L or Kg)	Titrametric	E310.1	50	250	--	--	--
Total Kjeldahl Nitrogen	Digestion & Colorimetric	E351.2	0.06	1.2	--	--	--
Phosphorous (total)	Digestion & Colorimetric	E365.4	0.2	4	--	--	--
pH (Soil)	pH Electrode	SW9045A	0.1 pH Unit Range 1-14	0.1 pH Unit Range 1-14	--	--	--
PETROLEUM HYDROCARBONS (mg/l or mg/kg)							
Total Recoverable Petroleum Hydrocarbons	IR	SW9071 extraction & E418.1	0.5	10	--	—	--
SOIL GAS (mg/m^3)							
BTEX and Total Petroleum Hydrocarbons	GC/PID/ FID	SW8020/ 8015 (Mod.)	--	BTEX (Gas) 0.05 mg/m^3 TPH (Gas) 20 mg/m^3	--	--	--

Table 3-2. Analytical Methods, Method Reporting Limits, and Maximum Contaminant Levels

[a] The method Reporting Limit (RL) is the minimum concentration of a substance that can be measured and reported for multiple instruments. RLs are highly matrix dependent and may not always be achievable. The RLs are set at 3-5 times the derived Method Detection Limit (MDL) determined in accordance with 40 CFR 136 App. B. RLs listed in this table are based on wet weight.

[b] Federal Drinking Water Standards Maximum Contaminant Levels (MCL), Office of Drinking Water, /USEPA.

[c] Values calculated using the reference dose (RfD) or slope factor (SF) with EPA's method for calculating action levels (Appendix 4 of "Draft Preliminary Standards for RCRA Risk Assessment," EPA Region VI, 20 February 1991; and 27 July 1990 Fed. Reg., "Corrective Action for SWMUs at Hazardous Waste Management Facilities," Appendix E. The source of the RfD and SFs used in the calculation are designated by a footnote for each value in this column. Action levels may change over time, EPA IRIS database should be reviewed prior to using these levels in the decision-making process.

[d] Unless otherwise noted, RfDs or Sfs used to calculate HBL are from the Electronic Handbook of Risk Assessment Values, which lists values from both IRIS and HEAST.

[e] New Mexico Human Health Standard for Lead.

[f] SF used in calculation of HBL calculated using method in *Comparative Potency Approach for Estimating the Cancer Risk Associated with Exposure to Mixtures of Polycyclic Aromatic Hydrocarbons*, Interim Final, ICF-Clement Associates, Fairfax, Virginia, April 1, 1988.

GC	=	Gas Chromatography
ICPES	=	Inductively Coupled Plasma Emission Spectroscopy
IR	=	Infrared Spectrometry
FID	=	Flame Ionization Detector
PID	=	Photo Ionization Detector
(Gas)	=	Soil Gas Sample
ug/l	=	Microgram per Liter
mg/l	=	Milligram per Liter
ug/kg	=	Microgram per Kilogram
mg/kg	=	Milligram per Kilogram
mg/m^3	=	Milligram per Cubic Meter

3.2 Data Quality Calculations

Precision and accuracy are the two most important indicators of measurement data quality. Precision is a measure of variability associated with a measurement system. Accuracy expresses the degree to which a measured value agrees with the true value for a given parameter. Accuracy includes elements of both bias and precision. This section provides instructions for calculating data quality in terms of precision and accuracy.

For this project, precision will be assessed and controlled through the use of MS and MSD analyses. Acceptance criteria are listed in Table 3-1.

The RPD will be used to estimate precision for duplicate analyses and is calculated by:

$$RPD = \frac{X_1 - X_2}{(X_1 + X_2)/2} \times 100$$

For this project, accuracy of the measurement data will be assessed and controlled by sample recovery. These results will be used to control accuracy within acceptable limits by requiring that they meet specific criteria. As spiked samples are analyzed, recoveries will be calculated and compared with preestablished acceptance limits (see Table 3-1). Percent recovery is calculated as the measured value of the spiked sample less the measured value of the sample divided by the actual value of the spike times 100.

4.0 FIELD ACTIVITIES

Discussions pertaining to the field activities are detailed in the FOP, Volume I of this Work Plan. Specific procedures discussed include:

- Sampling locations and rationale (Section 2.0);
- Sample numbering system (Section 3.2);
- Sample handling and preservation procedures (Section 3.3);
- Decontamination procedures (Section 3.4);
- Field screening procedures (Section 3.5);
- Soil sampling procedures (Section 2.0);
- Sample chain-of-custody packing and transportation procedures (Section 3.3);
- Field documentation procedures (Section 3.7);
- Investigation Derived Waste (IDW) handling procedures (Section 6.0); and
- Associated procedural SOPs (Appendix A).

5.0 LABORATORY ANALYTICAL PROCEDURES

5.1 Analytical Methods

The methods and procedures that will be used to prepare and analyze samples are discussed in this section. Most chemical analyses will be performed according to the following publications:

- SW-846, Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, U.S. EPA, Office of Solid Waste and Emergency Response, Update 1, July 1992; and
- EPA, Methods for Chemical Analysis of Water and Wastes, EPA Publication No. 600/4-79-020, March 1983

Individual parameters and analytical methods to be followed are identified in Table A-1. Information is provided for soil and groundwater matrices. Section 3 provides tabular summaries of analyses to be performed on soil samples collected during installation of the bioventing wells.

The laboratory will perform instrument-specific demonstration of capability(DOC) and method detection limit (MDL) studies to demonstrate the ability to meet project-specific reporting limits. Analysis will only be performed on instruments with valid and current MDL and DOC studies.

5.1.1 Total Iron Metal Analysis by ICPES--SW-846 Method 6010A

Soil samples will be analyzed to determine concentrations of iron. Soil samples will be prepared according to EPA Method 3050A. Method 3050A describes acid digestion of soil samples for analysis by inductively-coupled plasma emission spectroscopy (ICPES).

Following acid digestion, metals will be determined by Method 6010A, which allows the simultaneous measurement of elements using ICPES. This method measures the element emitted by light optical spectrometry. Samples are nebulized and the resulting aerosol is transported to the plasma torch. Element-specific atomic-line emission spectra are produced, dispersed by a grating spectrometer, and monitored for intensity by photomultiplier tubes.

5.1.2 pH--SW-846 Method 9045A

Several soil samples will be analyzed by EPA Method 9045A to determine pH levels. Soil samples are mixed with reagent-grade water or a calcium chloride solution, depending on whether the soil is considered calcareous or non-calcareous, prior to analysis. The pH of the solution is determined electrometrically.

5.1.3 Soil Moisture Content--ASTM D-2216

The percent moisture will be determined by removing the moisture using a heating oven. A pre-weighed sample aliquot is dried and weighed again after drying to determine the moisture content of the soil.

5.1.4 Alkalinity in Soil--EPA Method 310.1 (modified for Soils as appropriate)

Soil samples are prepared for analysis by exposing 1 gram of sample to 50 milliliters (ml) deionized water under stirring for 30 minutes. The resulting solution is then analyzed for alkalinity. Alkalinity is determined by titration of the aqueous solution with either sulfuric or hydrochloric acid to an endpoint pH of 4.5.

5.1.5 Total Phosphorous in Soil--EPA Method 365.4 (modified for Soils as appropriate)

Soil and aqueous samples are digested in the presence of sulfuric acid, dipotassium sulfate and mercuric sulfate. The residue is cooled, diluted and placed on an autoanalyzer for phosphorus determination. Total phosphorus determination is based on the colorimetric method in which a blue color is formed by the reaction of the phosphate, molybdate ion and antimony ion followed by reduction with ascorbic acid at an acidic pH. The phosphomolybdenum complex is read at 660 nanometers (nm).

5.1.6 Total Kjeldahl Nitrogen in Soil--EPA Method 351.2 (modified for Soils as appropriate)

Soil and aqueous samples are digested in the presence of sulfuric acid, dipotassium sulfate and mercuric sulfate. The determination of nitrogen is based on a colormetric method in which an emerald-green color is formed by the reaction of ammonia, sodium salicylate, sodium

nitroprusside and sodium hypochlorite (chlorine source) in a buffered alkaline medium at a pH of 12.8 - 13.0. The ammonia salicylate complex is read at 660 nm.

5.1.7 Total Recoverable Petroleum Hydrocarbons--EPA Method 418.1

Soil samples will be analyzed to determine the concentrations of fluorocarbon-113 extractable petroleum hydrocarbons present in the soil. Soil samples will be extracted following the soxhlet extraction method described in EPA Method 9071 using fluorocarbon-113. Total recoverable petroleum hydrocarbons (TRPH) will be determined by the infrared spectrophotometric method described EPA Method 418.1. TRPH are measured by the infrared spectrophotometric technique described in EPA Method 418.1.

5.1.8 Total BTEX--SW-846 Method 8020

Soil samples will be analyzed to determine concentrations of volatile organic compounds of benzene, toluene, ethylbenzene, and xylenes (BTEX). Samples are generally prepared utilizing a methanol extraction and preparation following SW-846 Method 5030. The analysis is performed on a GC with a photoionization detector and capillary column. The method is sensitive to benzene, substituted benzenes, and oxygenated compounds; less so to interfering aliphatics.

5.1.9 Soil Gas BTEX and Total Petroleum Hydrocarbon--SW-846 Methods 8020/8015 (Modified)

Extracted soil gas samples will be analyzed by purge and trap (EPA SW-846, Method 5030). A temperature program is used in the gas chromatograph to separate the organic compounds. Method 8020 detects aromatic volatile compounds achieved by a PID. Method 8015 detects certain nonhalogenated volatile organic compounds by the use of flame ionization detector (FID).

5.2 Geotechnical Analyses

The following geotechnical analyses will be conducted on selected soil samples, as identified in the FOP (Volume I) of this Work Plan:

- Atterburg Limits - ASTM Standard D4318.93
- Permeability - API Recommended Practice (RP) 40

Copies of the standard methods to be used are included in Appendix C.

5.3 Calibration Procedures

Documented calibration procedures are necessary to provide consistency in preparing equipment for specific analytical measurements. Established calibration procedures then provide a mechanism for ensuring that measurements made with a specific type of equipment are comparable. Calibration requirements for each analytical method used for this project are described in the following subsections and are summarized in Table A-2.

5.3.1 Metals by ICPES--SW-846 Method 6010A

SW-846 Method 6010A is used to measure elements with ICPES. Detailed calibration procedures for ICPES systems are described in SW-846, 3rd edition. A response factor is calculated daily for each metal on the basis of two determinations of a calibration standard and calibration blank. Following calibration, the high calibration check sample is analyzed: agreement between the measured value and the expected value must be within 5% for the analyses to proceed. Calibration is verified by analyzing a QC check standard which is prepared independently of calibration standards at a frequency of every 10 samples. Agreement within 10% of the expected value is required for all target analytes; otherwise, the system must be recalibrated. When a calibration check does not agree with the expected value ($\pm$10%), the samples that have been analyzed since the last calibration check are reanalyzed.

5.3.2 pH--SW-846 Method 9045A

Method 9045A is followed to electrometrically analyze samples for pH levels. Prior to sample analysis, the pH meter is calibrated with two standard buffer solutions. This calibration is performed daily.

5.3.3 Alkalinity--EPA Method 310.1

The acid titrant used for analysis is a purchased standard which is National Institute Standards and Technology (NIST)-traceable, and which has an expiration date. The solution is not used after the expiration date. The accuracy of the analysis is verified every 10 samples by analyzing a QC check sample and blank. Agreement within $\pm 10\%$ of the expected value is required.

5.3.4 Total Phosphorus--EPA Method 365.4

A multipoint calibration curve is generated daily using a calibration blank and five standards. The correlation coefficient for the linear regression equation must exceed 0.995 to be acceptable. Calibration will be verified every 10 samples by analyzing a QC check sample and calibration blank. Agreement within $\pm 10\%$ of the expected value is required; otherwise, a new calibration curve must be generated.

5.3.5 Total Kjeldahl Nitrogen--EPA Method 351.2

A multipoint calibration curve is generated daily using a calibration blank and five standards. The correlation coefficient for the linear regression equation must exceed 0.995 to be acceptable. Calibration will be verified every 10 samples by analyzing a QC check sample and calibration blank. Agreement within $\pm 10\%$ of the expected value is required; otherwise, a new calibration must be generated.

5.3.6 Total Recoverable Petroleum Hydrocarbons--EPA Method 418.1

TRPH are measured by the infrared spectrophotometric technique described in EPA Method 418.1. An initial multipoint curve must have a calculated correlation coefficient of 0.995 or greater. Continuing calibration check standards are analyzed daily and must be measured within $\pm 10\%$ of expected value.

5.3.7 Total BTEX--SW-846 Method 8020

Initial Calibration (IC) is performed as described in SW-846. Method 8000, a five-point calibration, is used to generate response factors. The relative standard deviation (RSD) must

be less than 20%. IC is required after instrument repair, column change or failure of Initial Calibration Verification (ICV) or Continuing Calibration Verification (CCV). An ICV consisting of a mid-range standard is analyzed after the calibration to verify the calibration. The CCV is analyzed daily before analysis starts and thereafter at a 10% frequency. The CCV must be within 15% of the average multipoint response factor (RF).

5.3.8 Total Soil Gas BTEX and Total Petroleum Hydrocarbons--SW846 Methods 8020/8015 (Modified)

IC is performed as described in SW-846. Method 8000, a five-point calibration is used to generate response factors. The RSD must be less than 20%. IC is required after instrument repair, column change or failure of ICV or CCV. An ICV consisting of a mid-range standard is analyzed after the calibration to verify the calibration. The CCV is analyzed daily before analysis starts and thereafter at a 10% frequency. The CCV must be within 15% of the average multipoint RF.

5.4 Preventative Maintenance

The primary objective of the preventive maintenance program is to help ensure the timely and effective completion of a measurement effort. A preventive maintenance program is designed to minimize the down-time of crucial sampling and/or analytical equipment because of expected or unexpected component failure. In implementing this program, efforts are focused in three primary areas:

- Establishment of maintenance responsibilities;
- Establishment of maintenance schedules for major and/or critical instrumentation and apparatus; and
- Establishment of an adequate inventory of critical spare parts and equipment.

Each of these efforts are discussed in the following sections.

5.4.1 Maintenance Responsibilities

Equipment and apparatus used in environmental measurement programs fall into two general categories:

- Equipment that is permanently assigned to a specific laboratory (e.g., metals laboratory, GC laboratory, etc.); and
- Equipment that is available for field or laboratory use on an as-needed basis (e.g., field sampling equipment, mobile laboratory, etc.).

Maintenance responsibilities for permanently-assigned equipment are assigned to the respective laboratory managers. The laboratory managers then establish maintenance procedures and schedules for each major equipment item. Specific responsibilities for specific items may be delegated to laboratory personnel, although the laboratory managers retain responsibility for ensuring adherence to prescribed protocol.

Non-assigned equipment includes field pH and conductivity meters, water-level meters, thermometers, real-time monitoring instrumentation, and organic vapor analysis instrumentation. Equipment in this category requires three related maintenance efforts:

- Ensuring that available equipment is functional and ready for use;
- Maintenance during use; and
- Check-out and servicing after use.

5.4.2 Maintenance Schedules

The effectiveness of any maintenance program depends to a large extent on adherence to specific maintenance schedules for each major equipment item. Table 5-1 indicates the schedule for all routine maintenance activities. Note that this schedule will be subject to change should conditions warrant. Other maintenance activities may also be identified as requiring attention on an as-needed basis. In addition, field testing equipment (e.g., pH meters) will be inspected prior to use and serviced or replaced as necessary. Manufacturers' recommendations provide the primary basis for the established maintenance schedules, and

manufacturers' service personnel provide primary maintenance for many major instruments (e.g, GC/MS instruments, atomic absorption spectrometers, analytical balances, etc.). Maintenance activities are documented in a maintenance log, which indicates the required frequency for each procedure and provides for dated entries.

5.4.3 Spare Parts

Along with a schedule for maintenance activities, an adequate inventory of spare parts required to minimize equipment down time. This inventory should emphasize those parts (and supplies) that:

- Are subject to frequent failure;
- Have limited useful lifetimes; or
- Cannot be obtained promptly should failure occur.

Table 5-1 Instrument Maintenance Schedule

Instrument	Maintenance	Frequency
AA	Tuning/Service Call Clean Fan Filter Replace Lamps Change Tubing Clean Windows Clean of Replace Cones	Quarterly Annually As Needed As Needed As Needed As Needed
ICPES	Check Disc Drive Run Diagnostics Clean Torch Clean Nebulizer Clean Fan Filter Replace Pump Oil Replace Tubing	Daily Daily Weekly Weekly Monthly Quarterly As Needed
GC/MS	Clean Fan Filter Replace Vacuum Pump Oil Replace Filaments Clean Ion Source Replace Electron Multipliers Replace Septa Replace Column Replace Injector Liners Replace Organic Filters Replace Oxygen Traps	Quarterly Semi-Annually As Needed As Needed As Needed As Needed As Needed As Needed As Needed As Needed
GC	Purge traps are baked out Columns are baked out Septa are replace after 30 injections Teflon ferrules are replaced Injector Liners replaced Instrument electronics are visually inspected and cleaned Detectors are cleaned on schedule recommended by the manufacturer	Daily Daily Daily Weekly Weekly Quarterly Quarterly Quarterly
GC/PID/ELCD	Clean PID Lamp Replace Lamp Replace Furnace Tube Replace Propanol Replace Resin	As Needed As Needed As Needed As Needed As Needed
Balances	Service	Annually

Table 5-1 Instrument Maintenance Schedule (Cont.)

Instrument	Maintenance	Frequency
OVA/FID	Recharge or Replace Battery Monitor Fuel and/or Combustion Air Supply Gauges Perform Routine Maintenance as Described in the Manual Check for Leaks	As Needed Hourly As Needed Daily
PID	Recharge or Replace Battery Replace or Clean Lamps Clean or Replace Filter Check for Leaks	As Needed As Needed As Needed Daily
pH Meter	Check Fuse and Sensor Clean Motor Rinse Probe	Weekly As Needed After Each Measurement
Conductivity Meter	Clean Meter Recharge or Replace Battery	As Needed As Needed
Water Level Meter	Clean Meter Wipe Probe Dry and Place Into Probe Holder Recharge or Replace Battery	As Needed After Each Measurement As Needed
Thermometer	Clean Replace	As Needed If broken or mercury separates

Notes:
AA = Atomic Absorption
ICPES = Inductively Coupled Plasma Emission Spectroscopy
GFAA = Graphite Furnace Atomic Absorption
GC/MS = Gas Chromatography/Mass Spectrometry
GC/PID/ELCD = Gas Chromatography/Photoionization Detector/Electron Conductivity Detector
PID = Photoionization Detector
OVA/FID = Organic Vapor Analyzer/Flameionization Detector

The supervising field task managers and the respective laboratory managers will be responsible for maintaining an adequate inventory of necessary spare parts. Field task leaders will have names and phone numbers of vendor contacts to ensure that replacement parts or instrumentation can be received within 24 hours of instrument failure.

5.5 Internal Quality Control

Internal QC procedures to be used for laboratory testing and analysis are presented in Table A-3. Tables A-4, A-5, and A-6 present detailed listings of tolerance limits for QCCs, matrix spike analyses, and surrogate spike recoveries, respectively. Preparation and analysis of QC samples will be according to the descriptions presented in this section.

Most analytical methods to be used in this project require the measurement system to initially satisfy specific criteria for calibration linearity, reference material recovery, and freedom from contamination. Results of control samples, which are analyzed at a 10% frequency to monitor any changes in the quality of data being produced, indicate which corrective actions are necessary to correct an out-of-control conditions. An out-of-control condition is defined as:

- Detection of any compounds of interest in a method blank at concentrations equal to or greater than the reporting limit (or required detection limit);
- Failure to meet the acceptance criteria for recovery of any compound of interest in a QC sample; or
- Exceeding the acceptance criteria for matrix spike recovery and subsequent failure to meet the acceptance criteria for a QC check sample for the same parameter(s). Any parameter that fails the matrix spike test but passes the QC check sample test will be flagged as suspect for the parameter due to matrix effects.

When an out-of-control situation is detected, efforts will be undertaken to determine the case. Corrective actions for routine QC checks are outlined in Tables A-2 and A-3. Procedures related to corrective actions are described below.

During the course of this project, it will be the responsibility of the laboratory staff, project manager, task leaders, and other project team members to see that all measurement procedures are followed as specified and that measurements data meet the prescribed acceptance criteria. In the event a problem arises, it is imperative that prompt action be taken to correct the problem(s). Laboratory analysts and/or supervisors will initiate corrective

action in the event of QC results that exceed acceptance criteria specified in Tables A-2 and A-3. Corrective action may also be initiated upon identification of some other problems or potential problems. Corrective action may also be initiated by the laboratory quality officer if QC data problems or other anomalies are noted during data review. Within 24 hours of the identification of a QC problem that will compromise data quality, the USACE project manager or chemist will be verbally notified.

For this project, the following corrective actions will be implemented when surrogate spike compounds are recovered outside the acceptability limits:

- Check to be sure there are no errors in calculations, surrogate solutions, and internal standards. Also, check instrument performance;
- Recalculate the data and/or reanalyze the extract if any of the above checks reveal a problem;
- Analyze an extracted LCS;
- If the LCS compounds are recovered within criteria, flag data as matrix effect; and
- If the LCS compounds are recovered outside criteria, re-extract and reanalyze the sample.

The analysis with the fewest control problems will be reported. A brief description of the other analysis and the corrective action taken will be included in the laboratory report. These corrective actions are summarized in Table A-3.

5.5.1 Method Blank

A method blank is an aliquot of reagent water or clean solid matrix, taken through the analytical process as though it were an actual sample. The purpose of a method blank analysis is to monitor and control laboratory sources of contamination. At a minimum, one laboratory

method blank will be analyzed daily for volatile organic method and each preparatory batch will have a method blank analyzed for semivolatile analyses and inorganic analyses.

5.5.2 Matrix Spike

A MS for metals and inorganic analyses is an aliquot of a field sample spiked with known concentrations of reference materials and taken through the entire preparation and analytical measurement procedures. A MS for organic analyses is an extra field sample spiked with known concentrations of reference materials and taken through the entire preparation and analytical measurement procedures. The MS allows the laboratory to assess the efficiency of extraction/digestion, accuracy of the analysis, and possible matrix effects. MS analyses will be performed on a 5% frequency for each batch as required by SW-846. Note: The soil sampling for chemical analyses and groundwater sampling for chemical analyses SOPs (SOP A-6 and A-9, respectively) provided in the FOP (Volume I) contain tables that stipulate sufficient sample volumes to accommodate the laboratory conducting the MS tests.

If method accuracy or precision, as demonstrated with matrix spikes or real samples or laboratory duplicates, fall outside the acceptability limits a quality control sample will be analyzed immediately. If the analytical system is shown to be in control with acceptable QC sample results, then an investigation is initiated and the sample in question will be re-analyzed at no cost to the customer if required to verify that the problem is reproducible and hence related to the sample. If the analytical system is found to be at fault, then the problem will be corrected and all samples affected will be re-analyzed at no cost to the customer, including those prior to the sample in question, all of the way back to the previous in-control QC sample.

5.5.3 Matrix Spike Duplicate

A MSD is a second aliquot of the matrix spike sample that is also spiked. Method precision for the matrix can be estimated by calculating the relative percent differences between the recoveries of the spiking compounds. MSD analyses will be performed on a 5% frequency for each batch. Note: As with the MS analyses, the soil and groundwater sampling SOPs (SOP A-

6 and A-9, respectively) in the FOP (Volume I) contain tables that stipulate sufficient sample volumes to accommodate the laboratory conducting of the MSD tests.

5.5.4 Duplicate Sample

Duplicate solid samples will be collected by splitting a single sample into two equal parts for the purpose of analysis. Duplicate water samples will be included in the project by collecting two samples from the same location at the same time. Unique sample numbers will be assigned to field duplicates so that they will be indistinguishable from other analytical samples. The purpose of collecting and analyzing duplicate samples is to provide a measure of method variability (i.e., total variability from imprecision in both sampling and analytical procedures). Duplicate samples and QA duplicates (analyzed by USACE MRD) are not to be conducted on this project per the USACE Scope of Services.

5.5.5 Laboratory Control Check Sample

A LCS is a sample having known concentrations of reference materials spiked into an aliquot of deionized water. It is taken through the sample preparation process as well as the analytical measurement process. The purpose of a LCS analysis is to determine whether failure to meet QC acceptance criteria is due to matrix interference in the sample or to out-of-control conditions associated with the analytical system.

5.5.6 Surrogate Compound

Surrogates are organic compounds that are similar to analytes of interest in chemical composition, extraction, and chromatography, but which are not normally found in environmental samples. These compounds are spiked into all blanks, standards, samples, and spiked samples prior to extraction and analysis by Method 8020. Percent recoveries are calculated and reported for each surrogate. Surrogate spike recoveries can be used to assess method accuracy of individual samples.

5.6 Corrective Action

During the course of the field investigation, it will be the contractor project manager's responsibility to notify the USACE project manager of any situation prompting significant changes that may affect data quality or any nonconforming items or activities which would initiate the corrective action process. Any work or materials not conforming to the specifications or contract requirements will be identified and documented on a Nonconformance Report (NCR), as indicated in Appendix B. At a minimum, the NCR will detail the nonconforming condition, recommended corrective action(s) and disposition of the corrective action(s). The NCR will remain open until the nonconforming condition has been satisfactorily resolved and verified by QC.

The disposition of the NCRs will include the necessary actions required to bring the nonconforming condition to an acceptable condition and may include reworking, replacing, retesting, or reinspecting. Implementation of the disposition may be done in accordance with the original procedural requirements, a specific procedure or instruction, or a Procedure Change Request Form (PCRF). Appropriate corrective actions to take will be determined by USACE. Monthly reports will include nonconfirmation notices of all circumstances associated with corrective actions taken.

The laboratory supervisor will be responsible to ensure that all measurement procedures are followed as specified and that measurement data meet the prescribed acceptance criteria. In the event a problem arises, it is imperative that prompt action be taken to correct the problem. Problems requiring major corrective action will be documented by the use of the "Malfunction Report" form. An example of such a form is presented in Appendix B. The project QAC will be included in the distribution for each malfunction report issued for this program to ensure prompt notification of the USACE project manager or chemist. The laboratory supervisor will initiate corrective action in the event that QC results that exceed acceptability limits or if some other problem or potential problem is identified.

Potential problems identified by the QAC on the basis of QC data or audit results will be documented by use of the "Information Request" form. An example of such a form is

presented in Appendix B. Corrective action may also be initiated by the QAC on the basis of QC data, audit results, or responses to information requests. The USACE project manager or chemist will be notified of significant problems for concurrence with implementation of corrective actions.

5.7 Quality Assurance Reporting

Effective management of a field sampling and analytical effort requires timely assessment and review of field activities. This will require effective interaction and feedback between the project manager, QAC, field team members, and USACE.

The project manager and appropriate project team members will be responsible for keeping the QAC up to date regarding the status of their respective tasks so that quick and effective solutions can be implemented should any data quality problems arise. The use of a DQCR also provides an effective mechanism for ensuring ongoing evaluation of measurement efforts. The DQCRs are submitted to the USACE project manager weekly. A DQCR is presented in Appendix C. These DQCRs address some or all of the following as appropriate:

- Weather conditions;
- Summary of activities and work performed;
- Summary of calibration data and QC data;
- Summary of unscheduled maintenance activities;
- Summary of problems and corrective actions taken;
- Health and safety levels and actions; and
- Work scheduled for the next day.

5.7.1 Quality Assurance Reporting

Major project reports will include a QA/QC section that summarizes QC data collected during the program, as well as any major QA problems and resolutions. The QA/QC section in the final report will include an assessment of measurement accuracy, precision, and completeness as described in Sections 4 and 5 of this QAPP. It will also summarize any QC problems and resolutions that occurred during sample collection and any analytical anomalies experienced.

Problems requiring swift resolution will be brought to the immediate attention of the USACE project manager via the malfunction reporting/corrective action scheme discussed in Section 5.6.

5.7.2 QAPP Revisions

In the event that changes to this QAPP are needed, the following steps will be taken:

- Identify and discuss the problems or deficiencies in the QAPP with the contractor's project manager and USACE project manager;
- The project team determines changes to be made;
- Potential changes will be submitted to USACE project manager for approval;
- When approved by USACE project manager, the QAPP revisions will be implemented by the project team;
- Revision to the QAPP will be documented by the use of Revision Numbers within the footers. The Draft Final Plan represents Revision 0;
- Complete sets of plans (FOP, QAPP, and SSHP) will be distributed on a controlled basis; and
- Revisions will be accompanied by a control distribution sheet which will specify what sections are being replaced. The control distribution sheet will require the copy holder to sign and return the sheet to the original point of distribution.

5.8 Data Reduction, Validation and Documentation

All analytical data generated will be extensively checked for accuracy and completeness. The data validation process consists of data generation, reduction, review, and reporting by the analytical laboratory. Data will be reviewed by the contractor QAC. Laboratory data reports will be submitted to USACE for QA review by USACE personnel.

5.8.1 Data Reduction, Validation, and Reporting by the Laboratory

The data analysis required to calculate sample concentrations will proceed according to procedures outlined in the analytical methods identified in Table A-1. Data reduction involves taking instrument responses or other raw data and calculating concentrations for each target analyte. Data validation involves examining the systems producing the data to be sure they are operating properly and quality objectives have been met. Data will be reviewed and validated by the analyst and/or laboratory manager. Data will be validated for conformance with method specifications including:

- Calibration;
- Duplicate analysis;
- Blank analysis;
- Spike analysis;
- Sample data calculations; and
- Quality control sample frequency.

The QC activities implemented in this project will provide a basis for assessing the accuracy and precision of all data. Frequencies and acceptance criteria for these tests are presented in Table A-3. Calculations are presented in Section 3.2 of this QAPP.

5.8.2 Data Review and Validation by the Contractor

In addition, data will be reviewed by the contractor who is an independent party not associated with the laboratory to ensure that analytical results received from the laboratory are valid and meet the QA objectives. Tables A-4, A-5, and A-6 provide tolerance limits for precision and accuracy. Data quality calculations used during this review to estimate precision and accuracy are presented in Section 3.2 of this QAPP.

6.0 QUALITY ASSURANCE AUDITS

The purpose of a QA audit is to provide an objective, independent assessment of a measurement effort. QA auditing ensures that sample collection, data generating, data gathering, and measurement activities produce reliable and useful results. Cases can occur in which inadequacies are identified in the measurement system. In such cases, audits provide the mechanism for beginning the process of corrective action implementation. With the exception of USACE MRD laboratory audits, no QA audits are scheduled. However, at the discretion of the Base or USACE, QA audits may be implemented. QA audits play an important role in an overall QA/QC program. This section provides descriptions of the role of the QA auditor and the nature of QA audits.

A QA auditor is the person who designs and/or performs QA performance and system audits. Since QA audits represent, by definition, independent assessments of a measurement system and associated data quality, the auditor must be functionally independent of the measurement effort to ensure objectivity. However, the auditor must be familiar enough with the objectives, principles, and procedures of the measurement efforts to be able to perform a thorough and effective evaluation of the measurement system. Especially important is the ability to identify components of the system that are critical to overall data quality. For this reason, the audit focuses heavily on those elements. The auditor's technical background and experience should also provide a basis for appropriate audit standard selection, audit design, and data interpretation.

QA audits may include both internal and external audits of field and laboratory activities. External audits are those conducted by an independent organization or technical support group and may include participation in inter-laboratory comparison studies and certification testing. Internal laboratory audits are conducted by the laboratory's QAC. External laboratory and field audits may be conducted by the contractor QAC if indicated during the program.

The following paragraphs describe the purpose of several types of audits and identify the questions that are, and are not, addressed by each type of audit.

6.1 Technical Systems Audits

A technical systems audit is an on-site qualitative review of the various aspects of a total sampling and/or analytical system. It is an assessment of overall effectiveness. It represents an objective and insightful evaluation of a set of interactive systems with respect to strengths, deficiencies, and potential areas of concern. Typically, the audit consists of observations and documentation of all aspects of the measurement effort.

Technical system audits should be based on the approved QAPP. These audits review questions regarding:

- Calibration procedures and documentation;
- Completeness of data forms, notebooks, and other reporting requirements;
- Data review and validation procedures;
- Data storage, filing, and record-keeping procedures;
- Sample custody procedures;
- Quality control procedures and documentation;
- Operating conditions of facilities and equipment;
- Documentation of maintenance activities; and
- Systems and operations overview.

Detailed systems audit checklists may be prepared prior to each audit. The checklist delineates the critical aspects of each methodology and measurement system, and are used by auditors to document all observations. The checklists are based on audit criteria specified by the QAC and the approved QAPP.

Technical systems audits do not answer quantitative questions about the measurement system. The organization's policies regarding the role of QA are not answered. Concerns involving assessments of the data quality indicators are also not addressed.

6.2 Performance Evaluation Audits

The purpose of performance evaluation audits is to quantitatively assess the measurement data quality. These audits provide a direct evaluation of the various measurement systems' capabilities to generate quality data. This is accomplished by challenging the measurement system with accepted reference standards. These reference standards may be submitted to the laboratory as if they were additional field samples, thereby providing a blind evaluation.

Performance evaluation audits answer questions regarding the following:

- Accuracy and precision of the measurement system;
- The quality control data as compared with the actual data collected;
- The measurement system as a function of established control limits; and
- Significant deviations of the quality over time.

Although the answers to these questions will help determine when a system is out of control, questions as to the appropriate corrective action may not always be evident. Questions regarding qualitative issues, such as management policies, sample custody procedures, record keeping, and data handling systems are not addressed in a performance evaluation audit.

6.3 Audits of Data Quality

The purpose of data quality audits is to assess data quality indicators. Audits for data quality provide information required to characterize data quality by answering questions regarding:

- Adequacy of data recording and transfer;

- Precision and bias of resultant data;
- Adequacy of data calculation, generation, and processing;
- Documentation of procedures; and
- Identification of data quality indicators to inform users of limitations and applicability.

Audits of data quality answer questions of whether the data collection efforts need modifications, and whether the use and documentation of QC procedures are adequate. Audits of data quality do not, however, answer technical questions such as those concerning the operating condition of facilities and equipment.

6.4 Post-audit Debriefing

Following each audit, a post-audit debriefing session is conducted. The purpose of this session is to discuss preliminary audit results with the audit participants. If the audit reveals a critical deficiency, recommendations for corrective action should be presented. The debriefing session is followed by a detailed audit report that identifies areas of concern and recommendations for corrective actions.

APPENDIX A -- TABLES

A-1 Analytical Methods

A-2 Summary of Calibration Procedures

A-3 Summary of Internal Quality Control Procedures

A-4 Summary of Tolerance Limits for Quality Control Check Samples

A-5 Summary of Limits for Matrix Spike Analyses

A-6 Summary of Surrogate Spike Tolerance Limits

A-7 Sample Container Requirements

Table A-1. Analytical Methods

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
METALS (ug/l or mg/kg)							
Aluminum	Acid Digestion	3010A	3050A	ICPES	6010A	200	20
Antimony	Acid Digestion	3005A	3050A	ICPES	6010A	200	20
Arsenic	Acid Digestion	3010A	3050A	ICPES	6010A	400	40
Barium	Acid Digestion	3010A	3050A	ICPES	6010A	200	20
Beryllium	Acid Digestion	3010A	3050A	ICPES	6010A	5	0.5
Cadmium	Acid Digestion	3010A	3050A	ICPES	6010A	20	2.0
Calcium	Acid Digestion	3010A	3050A	ICPES	6010A	5000	500
Chromium (total)	Acid Digestion	3010A	3050A	ICPES	6010A	30	3.0
Cobalt	Acid Digestion	3010A	3050A	ICPES	6010A	50	5.0
Copper	Acid Digestion	3010A	3050A	ICPES	6010A	25	2.5
Iron	Acid Digestion	3010A	3050A	ICPES	6010A	100	10
Lead	Acid Digestion	3010A	3050A	ICPES	6010A	70	7
Magnesium	Acid Digestion	3010A	3050A	ICPES	6010A	5000	500
Manganese	Acid Digestion	3010A	3050A	ICPES	6010A	15	1.5
Nickel	Acid Digestion	3010A	3050A	ICPES	6010A	40	4.0
Selenium	Acid Digestion	3010A	3050A	ICPES	6010A	200	20
Silver	Acid Digestion	3010A	3050A	ICPES	6010A	20	2.0
Sodium	Acid Digestion	3010A	3050A	ICPES	6010A	5000	500
Potassium	Acid Digestion	3010A	3050A	ICPES	6010A	5000	500

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
Thallium	Acid Digestion	3010A	3050A	ICPES	6010A	200	20
Vanadium	Acid Digestion	3010A	3050A	ICPES	6010A	50	5.0
Zinc	Acid Digestion	3010A	3050A	ICPES	6010A	20	2.0
Arsenic	Acid Digestion	3020A	3050A	GFAA	7060	10	1.0
Lead	Acid Digestion	3020A	3050A	GFAA	7421	4	0.4
Mercury	Acid Digestion	7470	7471A	CVAA	7470/7471	0.5	0.25
Selenium	Acid Digestion	3020A	3050A	GFAA	7740	10	1.0
Thallium	Acid Digestion	3020A	3050	GFAA	7841	5	0.5
VOLATILE ORGANICS (FIXED LABORATORY) (ug/l or ug/kg)							
Acetone	Purge and Trap	5030A	5030A	GC/MS	8240A	20	20
Benzene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
Bromodichloromethane	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
Bromomethane	Purge and Trap	5030A	5030A	GC/MS	8240A	10	10
Carbon disulfide	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
Carbon tetrachloride	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
Chloroethane	Purge and Trap	5030A	5030A	GC/MS	8240A	10	10
2-Chloroethyl vinyl ether	Purge and Trap	5030A	5030A	GC/MS	8240A	10	10
Chlorobenzene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
Chloroform	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
Chloromethane	Purge and Trap	5030A	5030A	GC/MS	8240A	10	10

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
Dibromochloromethane	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
1,2 Dichlorobenzene	Purge and Trap	5030A	5030A	GC/MS	8240A	10	10
1,3 Dichlorobenzene	Purge and Trap	5030A	5030A	GC/MS	8240A	10	10
1,4 Dichlorobenzene	Purge and Trap	5030A	5030A	GC/MS	8240A	10	10
1,2 Dichloroethane	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
cis-1,2-Dichloroethene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
trans-1,2-Dichloroethene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
1,1 Dichloroethane	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
1,1 Dichloroethene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
1,2 Dichloropropane	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
cis-1,3 Dichloropropene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
trans-1,3 Dichloropropene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
Ethylbenzene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
2 - Hexanone	Purge and Trap	5030A	5030A	GC/MS	8240A	20	20
Methylene chloride	Purge and Trap	5030A	5030A	GC/MS	8240A	10	10
2 Butanone (MEK)	Purge and Trap	5030A	5030A	GC/MS	8240A	20	20
4-Methyl-2-pentanone (MIBK)	Purge and Trap	5030A	5030A	GC/MS	8240A	20	20
Styrene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
1,1,2,2-Tetrachloroethane	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
Tetrachloroethene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
Toluene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
Tribromomethane (Bromoform)	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
Trichloroethene	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
1,1,1-Trichloroethane	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
1,1,2-Trichloroethane	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
Vinyl acetate	Purge and Trap	5030A	5030A	GC/MS	8240A	20	20
Vinyl chloride	Purge and Trap	5030A	5030A	GC/MS	8240A	10	10
Xylenes (total)	Purge and Trap	5030A	5030A	GC/MS	8240A	5.0	5.0
BTEX, VOLATILE ORGANIC (MOBILE LABORATORY) (ug/l or ug/kg)							
Benzene	Purge and Trap	5030A	5030A	GC/PID	8020	0.5	0.05
Toluene	Purge and Trap	5030A	5030A	GC/PID	8020	1	0.1
Ethylbenzene	Purge and Trap	5030A	5030A	GC/PID	8020	1	0.1
Xylenes (total)	Purge and Trap	5030A	5030A	GC/PID	8200	2	0.2
TOTAL VOLATILE ORGANICS (MOBILE LABORATORY) (ug/l or mg/kg)							
Benzene	Purge and Trap	5030 Low	5030 Med	PID	8020	0.5	0.025
Bromodichloromethane	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
Bromomethane	Purge and Trap	5030 Low	5030 Med	ELCD	8010	1.0	0.030
Bromoform	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.5	0.010
Carbon tetrachloride	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
Chlorobenzene	Purge and Trap	5030 Low	5030 Med	ELCD/PID	8010/8020	0.5	0.025

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
Chloroethane	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.5	0.025
Chloroform	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.5	0.060
Chloromethane	Purge and Trap	5030 Low	5030 Med	ELCD	8010	1.0	0.025
Dibromochloromethane	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
1,2-dibromoethane (EDB)	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
1,2-dichlorobenzene	Purge and Trap	5030 Low	5030 Med	ELCD/PID	8010/8020	0.5	0.025
1,3-dichlorobenzene	Purge and Trap	5030 Low	5030 Med	ELCD/PID	8010/8020	0.5	0.025
1,4-dichlorobenzene	Purge and Trap	5030 Low	5030 Med	ELCD/PID	8010	0.5	0.025
1,1-dichloroethane	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
1,2-dichloroethane (EDC)	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.5	0.010
1,1-dichloroethene	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
cis-1,2-dichloromethene	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
trans-1,2-dichloromethene	Purge and Trap	5030 Low	5030 Med	ELCD	8010	1.0	0.010
1,2-dichloropropene	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
cis-1,3-dichloropropene	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
trans-1,3-dichloropropene	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
ethyl benzene	Purge and Trap	5030 Low	5030 Med	PID	8020	0.5	0.025
methylene chloride	Purge and Trap	5030 Low	5030 Med	ELCD	8010	2.0	0.50
1,1,2,2-tetrachloroethane	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
tetrachloroethylene	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.5	0.025

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
Toluene	Purge and Trap	5030 Low	5030 Med	PID	8020	0.5	0.025
1,1,1-trichloroethane	Purge and Trap	5030 Low	5030 Med	ELCD	8010	1.0	0.050
1,1,2-trichloroethane	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
trichloroethene	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
trichlorofluoromethane	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.2	0.010
vinyl chloride	Purge and Trap	5030 Low	5030 Med	ELCD	8010	0.5	0.025
total xylenes	Purge and Trap	5030 Low	5030 Med	PID	8020	0.5	0.025
2-chloroethylvinyl ether	Purge and Trap	5030 Low	5030 Med	ELCD	8010	1.0	0.050
SEMI-VOLATILE ORGANIC (ug/l or ug/kg)							
Acenaphthene	Extraction	3510A	3550	GC/MS	8270A	10	330
Acenaphthylene	Extraction	3510A	3550	GC/MS	8270A	10	330
Anthracene	Extraction	3510A	3550	GC/MS	8270A	10	330
Benzo(a)antracene	Extraction	3510A	3550	GC/MS	8270A	10	330
Benzo(a)pyrene	Extraction	3510A	3550	GC/MS	8270A	10	330
Benzo(b)fluorathene	Extraction	3510A	3550	GC/MS	8270A	10	330
Benzo(g,h,i)perylene	Extraction	3510A	3550	GC/MS	8270A	10	330
Benzo(k)fluoranthene	Extraction	3510A	3550	GC/MS	8270A	10	330
Benzoic acid	Extraction	3510A	3550	GC/MS	8270A	50	1700
Benzyl alcohol	Extraction	3510A	3550	GC/MS	8270A	20	670
4-Bromophenyl phenyl ether	Extraction	3510A	3550	GC/MS	8270A	10	330

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
Butylbenzylphthalate	Extraction	3510A	3550	GC/MS	8270A	10	330
4-Chloro-3-methylphenol	Extraction	3510A	3550	GC/MS	8270A	20	670
4-Chloroaniline	Extraction	3510A	3550	GC/MS	8270A	50	1700
bis(2-Chloroethoxy)methane	Extraction	3510A	3550	GC/MS	8270A	10	330
bis(2-Chloroethyl)ether	Extraction	3510A	3550	GC/MS	8270A	10	330
bis(2-Chloroisoprophyl)ether	Extraction	3510A	3550	GC/MS	8270A	10	330
2-Chloronaphthalene	Extraction	3510A	3550	GC/MS	8270A	10	330
2-Chlorophenol	Extraction	3510A	3550	GC/MS	8270A	10	330
4-Chlorophenyl phenyl ether	Extraction	3510A	3550	GC/MS	8270A	10	330
Chrysene	Extraction	3510A	3550	GC/MS	8270A	10	330
Dibenz(a,h)anthracene	Extraction	3510A	3550	GC/MS	8270A	10	330
Dibenzofuran	Extraction	3510A	3550	GC/MS	8270A	10	330
1,2-Dichlorobenzene	Extraction	3510A	3550	GC/MS	8270A	10	330
1,3-Dichlorobenzene	Extraction	3510A	3550	GC/MS	8270A	10	330
1,4-Dichlorobenzene	Extraction	3510A	3550	GC/MS	8270A	10	330
3,3-Dichlorobenzidine	Extraction	3510A	3550	GC/MS	8270A	20	670
2,4-Dichlorophenol	Extraction	3510A	3550	GC/MS	8270A	10	330
Diethylphthalate	Extraction	3510A	3550	GC/MS	8270A	10	330
2,4-Dimethylphenol	Extraction	3510A	3550	GC/MS	8270A	10	330
4,6-Dinitro-2-methylphenol	Extraction	3510A	3550	GC/MS	8270A	50	1700

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
Di-n-butylphthalate	Extraction	3510A	3550	GC/MS	8270A	10	330
Di-n-octylphthalate	Extraction	3510A	3550	GC/MS	8270A	10	330
1,3-Dinitrobenzene	Extraction	3510A	3550	GC/MS	8270A	10	330
2,4-Dinitrophenol	Extraction	3510A	3550	GC/MS	8270A	50	1700
2,4-Dinitrotoluene	Extraction	3510A	3550	GC/MS	8270A	10	330
2,6-Dinitrotoluene	Extraction	3510A	3550	GC/MS	8270A	10	330
bis(2-Ethylhexyl)phthalate	Extraction	3510A	3550	GC/MS	8270A	10	330
Fluorene	Extraction	3510A	3550	GC/MS	8270A	10	330
Hexachlorobenzene	Extraction	3510A	3550	GC/MS	8270A	10	330
Hexachlorobutadiene	Extraction	3510A	3550	GC/MS	8270A	10	330
Hexachlorocyclpentadiene	Extraction	3510A	3550	GC/MS	8270A	10	330
Hexachloroethane	Extraction	3510A	3550	GC/MS	8270A	10	330
Indeno(1,2,3-c,d)pyrene	Extraction	3510A	3550	GC/MS	8270A	10	330
Isophorone	Extraction	3510A	3550	GC/MS	8270A	10	330
2-Methyl naphthalene	Extraction	3510A	3550	GC/MS	8270A	10	330
2-Methylphenol	Extraction	3510A	3550	GC/MS	8270A	10	330
4-Methylphenol	Extraction	3510A	3550	GC/MS	8270A	10	330
Naphthalene	Extraction	3510A	3550	GC/MS	8270A	10	330
2-Nitroaniline	Extraction	3510A	3550	GC/MS	8270A	50	1700
3-Nitroaniline	Extraction	3510A	3550	GC/MS	8270A	50	1700

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
4-Nitroaniline	Extraction	3510A	3550	GC/MS	8270	50	1700
Nitrobenzene	Extraction	3510A	3550	GC/MS	8270A	10	330
2-Nitrophenol	Extraction	3510A	3550	GC/MS	8270A	10	330
4-Nitrophenol	Extraction	3510A	3550	GC/MS	8270A	50	1700
N-Nitrosodiphenylamine	Extraction	3510A	3550	GC/MS	8270A	10	330
N-Nitroso-di-n-propylamine	Extraction	3510A	3550	GC/MS	8270A	10	330
Pentachlorophenol	Extraction	3510A	3550	GC/MS	8270A	50	1700
Phenanthrene	Extraction	3510A	3550	GC/MS	8270A	10	330
Phenol	Extraction	3510A	3550	GC/MS	8270A	10	330
Pyrene	Extraction	3510A	3550	GC/MS	8270A	10	330
1,2,4-Trichlorobenzene	Extraction	3510A	3550	GC/MS	8270A	10	330
2,4,5-Trichlorophenol	Extraction	3510A	3550	GC/MS	8270A	10	330
2,4,6-Trichorophenol	Extraction	3510A	3550	GC/MS	8270A	10	330
ORGANOCHLORINE PESTICIDES & PCBs (ug/l or ug/kg)							
Aldrin	Extraction	3510A	3550	GC/EDC	8080	0.02	1
α-BHC	Extraction	3510A	3550	GC/EDC	8080	0.02	1
β-BHC	Extraction	3510A	3550	GC/EDC	8080	0.02	1
δ-BHC	Extraction	3510A	3550	GC/EDC	8080	0.02	1

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
γ-BHC	Extraction	3510A	3550	GC/EDC	8080	0.02	1
Chlordane	Extraction	3510A	3550	GC/EDC	8080	0.2	10
4,4'-DDD	Extraction	3510A	3550	GC/EDC	8080	0.02	1
4,4'-DDE	Extraction	3510A	3550	GC/EDC	8080	0.02	1
4,4'-DDT	Extraction	3510A	3550	GC/EDC	8080	0.02	1
Dieldrin	Extraction	3510A	3550	GC/EDC	8080	0.02	1
Endosulfan I	Extraction	3510A	3550	GC/EDC	8080	0.02	1
Endosulfan II	Extraction	3510A	3550	GC/EDC	8080	0.02	1
Endosulfan Sulfate	Extraction	3510A	3550	GC/EDC	8080	0.02	1
Endrin	Extraction	3510A	3550	GC/EDC	8080	0.02	1
Endrin Aldehyde	Extraction	3510A	3550	GC/EDC	8080	0.02	1
Heptachlor	Extraction	3510A	3550	GC/EDC	8080	0.02	1
Heptachlor Epoxide	Extraction	3510A	3550	GC/EDC	8080	0.02	1
Toxaphene	Extraction	3510A	3550	GC/EDC	8080	0.4	20
PCB 1016	Extraction	3510A	3550	GC/EDC	8080	0.2	10
PCB 1221	Extraction	3510A	3550	GC/EDC	8080	0.2	10
PCB 1232	Extraction	3510A	3550	GC/EDC	8080	0.2	10
PCB 1242	Extraction	3510A	3550	GC/EDC	8080	0.2	10
PCB 1248	Extraction	3510A	3550	GC/EDC	8080	0.2	10
PCB 1254	Extraction	3510A	3550	GC/EDC	8080	0.2	10

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
PCB 1260	Extraction	3510A	3550	GC/EDC	8080	0.2	10
HERBICIDES (ug/l or ug/kg)							
2,4-D	Extraction	3510A	3550	GC/EDC	8150A	10	330
2,4-DB	Extraction	3510A	3550	GC/EDC	8150A	10	330
2,4,5-TP (Silvex)	Extraction	3510A	3550	GC/EDC	8150A	2	67
2,4,5-T	Extraction	3510A	3550	GC/EDC	8150A	2	67
Dalapon	Extraction	3510A	3550	GC/EDC	8150A	60	2000
Dicamba	Extraction	3510A	3550	GC/EDC	8150A	3	100
Dichlorprop	Extraction	3510A	3550	GC/EDC	8150A	10	330
Dinoseb	Extraction	3510A	3550	GC/EDC	8150A	1	33
MCPA	Extraction	3510A	3550	GC/EDC	8150A	25000	83000
MCPP	Extraction	3510A	3550	GC/EDC	8150A	2000	67000
TCLP METALS (mg/l)							
Barium	Extraction/ Acid Digestion	N/A	1311/3010A	ICPES	6010A	1.0	N/A
Cadmium	Extraction/ Acid Digestion	N/A	1311/3010A	ICPES	6010A	0.05	N/A
Chromium	Extraction/ Acid Digestion	N/A	1311/3010A	ICPES	6010A	0.05	N/A
Silver	Extraction/ Acid Digestion	N/A	1311/3010A	ICPES	6010A	0.05	N/A

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
Arsenic	Extraction/ Acid Digestion	N/A	1311/3010A	GCAA	6010A	0.5	N/A
Lead	Extraction/ Acid Digestion	N/A	1311/3010A	GCAA	6010A	0.5	N/A
Mercury	Extraction/ Acid Digestion	N/A	1311/7470	GCAA	7470	0.002	N/A
Selenium	Extraction/ Acid Digestion	N/A	1311/3010A	GCAA	6010A	0.2	N/A
TCLP VOLATILES (mg/l)							
1,1-Dichloroethylene	Purge and Trap	N/A	1311/5030A	GC/MS	8240A	0.05	N/A
Benzene	Purge and Trap	N/A	1311/5030A	GC/MS	8240A	0.05	N/A
Carbon tetrachloride	Purge and Trap	N/A	1311/5030A	GC/MS	8240A	0.05	N/A
Chlorobenzene	Purge and Trap	N/A	1311/5030A	GC/MS	8240A	0.05	N/A
Chloroform	Purge and Trap	N/A	1311/5030A	GC/MS	8240A	0.05	N/A
1,2 Dichloroethane	Purge and Trap	N/A	1311/5030A	GC/MS	8240A	0.05	N/A
Methyl ethyl ketone (MEK)	Purge and Trap	N/A	1311/5030A	GC/MS	8240A	0.20	N/A
Tetrachloroethylene	Purge and Trap	N/A	1311/5030A	GC/MS	8240A	0.05	N/A
Trichloroethylene	Purge and Trap	N/A	1311/5030A	GC/MS	8240A	0.05	N/A
Vinyl chloride	Purge and Trap	N/A	1311/5030A	GC/MS	8240A	0.10	N/A
TCLP PESTICIDES (mg/l)							
Chlordane	TCLP	N/A	1311/3510A	GC/ECD	8080	0.0001	N/A

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
Endrin	TCLP	N/A	1311/3510A	GC/ECD	8080	0.0001	N/A
Heptachlor	TCLP	N/A	1311/3510A	GC/ECD	8080	0.0001	N/A
Heptachlor Epoxide	TCLP	N/A	1311/3510A	GC/ECD	8080	0.0001	N/A
Lindane (gamma-BHC)	TCLP	N/A	1311/3510A	GC/ECD	8080	0.0001	N/A
Methoxychlor	TCLP	N/A	1311/3510A	GC/ECD	8080	0.0001	N/A
Toxaphene	TCLP	N/A	1311/3510A	GC/ECD	8080	0.0004	N/A
TCLP HERBICIDES (mg/l)							
2,4-D	TCLP	N/A	1311/3510A	GC/ECD	8150A	0.0004	N/A
2,4,5-TP (Silvex)	TCLP	N/A	1311/3510A	GC/ECD	8150A	0.0001	N/A
TCLP SEMI - VOLATILES (mg/l)							
Pyridine	TCLP	N/A	1311/3510A	GC/MS	8270A	0.033	N/A
1,4-Dichlorobenzene	TCLP	N/A	1311/3510A	GC/MS	8270A	0.033	N/A
2-Methylphenol (o-Cresol)	TCLP	N/A	1311/3510A	GC/MS	8270A	0.033	N/A
3 + 4-Methylphenol (m-Cresol + p-Cresol)	TCLP	N/A	1311/3510A	GC/MS	8270A	0.033	N/A
Hexachloroethane	TCLP	N/A	1311/3510A	GC/MS	8270A	0.033	N/A
Nitrobenzene	TCLP	N/A	1311/3510A	GC/MS	8270A	0.033	N/A
Hexachloro-1,3-butadiene	TCLP	N/A	1311/3510A	GC/MS	8270A	0.033	N/A
2,4,6-Trichlorophenol	TCLP	N/A	1311/3510A	GC/MS	8270A	0.033	N/A

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
2,4,5-Trichlorophenol	TCLP	N/A	1311/3510A	GC/MS	8270A	0.033	N/A
2,4-Dinitrotoluene	TCLP	N/A	1311/3510A	GC/MS	8270A	0.033	N/A
Hexachlorobenzene	TCLP	N/A	1311/3510A	GC/MS	8270A	0.033	N/A
Pentachlorophenol	TCLP	N/A	1311/3510A	GC/MS	8270A	0.17	N/A
GENERAL							
Alkalinity	Titration	E310.1	E310.1 (Modified)	Titration	E310.1	50 mg/l	250 mg/kg
Kjeldahl Nitrogen (Total)	Digestion	E351.2	E351.2 (Modified	Colorimetric	E351.2	0.06 mg/l	1.2 mg/kg
Phosphorous (Total)	Digestion	E365.4	E365.4 (Modified)	Colorimetric	E365.4	0.2 mg/l	4 mg/kg
Flashpoint	N/A	1010	N/A	Closed cup	1010	60-200°F	N/A
pH (hydrogen ion concentration)	Electrode	9045A	9040	Electrode	9040/9045A	1-14	1-14
Soil Moisture	Thermal drying	N/A	ASTM D2216	Weigh	ASTM D2216	N/A	0-100%

Table A-1. Analytical Methods (Continued)

Parameter	Preparation			Analysis		Reporting Limit	
	Technique	Method Water	Method Soil	Technique	Method (Water/ Soil)	Water	Soil
PETROLEUM HYDROCARBONS (FIXED AND MOBILE LABORATORY)							
Oil and grease	Extraction	413.1	SW9071	Gravimetric	413.1/9071	5.0 mg/l	100 mg/kg
Total Petroleum Hydrocarbons, TPH as Diesel	Extraction	3510A	3550	GC/FID	Mod.8015	100 ug/l	10 mg/kg
Total Petroleum Hydrocarbons TPH as Gas	Purge and Trap	5030A	Mod.8015	GC/FID	Mod.8015	100 ug/l	10 mg/kg
Total Recoverable Petroleum Hydrocarbons (TRPH)	Extraction (SW9071 for soils)	418.1	SW9071 and 418.1	IR	418.1	0.5 mg/l	10 mg/kg
Soil Gas BTEX TPH as JP-4	Purge and Trap	N/A	Mod. 5030 (Gas)	GC/PID/FID	8020/Mod. 8015	--	BTEX 0.05 mg/m^3 TPH 20 mg/m^3

[a] Reporting limit is the minimum concentration of a substance that can be measured and reported for multiple instruments. Reporting limits are highly matrix dependent and may not always be achievable. Reporting limits provided in this table are based on method detection limits and practical quantitation limit guidance found in SW-846, but are not MDLs or PQLs. Reporting limits listed are on a wet-weight basis.

[b] Tentatively Identified Compound

ICPES = Inductively Coupled Plasma Emission Spectroscopy
GFAA = Graphite Furnace Atomic Absorption
GC/MS = Gas Chromatography/Mass Spectrometry
CVAA = Cold Vapor Atomic Absorption
PID = Photoionization Detector
TCLP = Toxicity Characteristic Leaching Procedure
ELCD = Electron Conductivity Detector
ECD = Electron Captive Detector
MDL = Method Detection Limit
IR = Infrared Spectrometry
N/A = Not Applicable

ug/l = Microgram per Liter
mg/l = Milligram per Liter
ug/kg = Microgram per Kilogram
mg/kg = Milligram per kilogram
mg/m^3 = Milligram per Cubic Meter
TPH = Total Petroleum Hydrocarbons
TRPH = Total Recoverable Petroleum Hydrocarbons
PQL = Practical Quantitative Limit
BTEX = Benzene, Toluene, Ethylbenzen, and Xylenes
FID = Flameionization Detector
(Gas) = Soil Gas Sample

Table A-2. Summary of Calibration Procedures

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
EPA:418.1	TRPH	Multipoint Calibration (minimum of five concentrations)	Initial	$r \geq 0.99$ and RSD of RFs < 10%	Repeat calibration
		Continuing Calibration Check	Daily and 10%	Measured value ± 10% of true value	Repeat calibration
SW-846:6010	Metals (ICPES)	Mixed Calibration Standards (2 Concentrations)	Daily, and 10%	Measured value ± 10% of true value for element of interest	Repeat calibration
SW-846:7060 SW-846:7421 SW-846:7471 SW-846:7740 SW-846:7841	Metals Arsenic (AA) Lead Mercury Selenium Thallium	Multipoint calibration (minimum of three concentrations)	Daily prior to analyses	$r \geq 0.995$	1) Repeat test 2) Take corrective action 3) Repeat calibration and test
		Calibration Blank	10%, or minimum of one per batch	<MRL	1) Clean system 2) Reanalyze

Table A-2. Summary of Calibration Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:8240A	Volatile Organic Compounds	Check of Mass Spectral Ion Intensities Using BFB	Daily prior to sample analyses or every 12 hours	Refer to Method 8240 Table 3	1) Retune instrument 2) Repeat BFB analyses
		Multipoint Calibration (5-point calibration at 10-200 ppb range)	Initial calibration and as required by calibration check	RSD<30% for average RF for CCCs and all SPCCs meet minimum RF criteria	Repeat calibration
		System Performance Check Compounds (SPCC) Calibration Check Compounds (CCC)	Every 12 hours	Minimum RF Criteria for SPCCs % Difference <25% for CCCs	1) Evaluate system 2) Repeat test 3) Recalibrate if repeat fails
SW-846:8270A	Semi-volatile Organic Compounds	Check of Mass Spectral Ion Intensities Using DFTPP	Daily and prior to sample analysis in every 12 hr.period	Refer to Method 8270 Table 3If	Retune instrument Repeat DFTPP analysis
		5-Point Calibration at 20-160 ppb Range	Initial and as required by daily check.	RF variability for specific CCC compounds <30% RSD	Repeat calibration
	Semi-volatile Organic Compounds	Calibration Verification for Calibration Check Compounds (CCC)	Every 12 hours	Single-point RF for each CCC within 30% of average multipoint RF	1) Evaluate system 2) Correct problems 3) Repeat test 4) Recalibrate if fails
		System Performance Check Compounds (SPCC)	Every 12 hours	RF > 0.05 for all SPCCs	1) Evaluate system 2) Correct problems 3) Repeat test 4) Recalibrate if fails
SW-846:8080	Organochlorine Pesticides & PCBs	Check Endrin & DDT Degradation	Daily prior to sample analysis	Degradation must be <20%,Refer to Method 8080 section 7.4.5	1) Retune instrument 2) Repeat DFTPP analysis
		5-Point Calibration	Initial and as required by daily check.	RSD for all RFs must be <20% if mean RF used for quant.	Repeat calibration or use a calibration curve for quant.

Table A-2. Summary of Calibration Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:8080 (Continued)	Organochlorine Pesticides & PCBs	Continuing Calibration Verification (CCV)	Daily and at 10% of all client sample	CCV recoveries must be within 15% of the predicted response	1) Evaluate system 2) Correct problems 3) Repeat test 4) Recalibrate if fails
SW-846:8150	Chlorinated Herbicides	5-Point Calibration	Initial and as required by daily check	RSD for all RFs must be <20% if mean RF used for quant.	Repeat calibration or use a calibration curve for quant.
		Initial Calibration Verification (ICV)	After initial calibration	ICV recoveries must be within 15% of the predicted response	1) Repeat calibration verification 2) Recalibrate if ICV fails
		Continuing Calibration Verification (CCV)	Daily prior to sample analysis and at 10% of client samples	CCV recoveries must be within 15% of the predicted response	1) Evaluate system 2) Correct problems 3) Repeat test 4) Recalibrate if fails
SW-846:8020 Modified for BTEX	Volatile Organics for BTEX	5-Point Calibration	Initial and as required by daily check	RSD for all RFs must be <20%	Retune instrument Repeat calibration analysis
		Initial Calibration Verification (ICV)	After initial calibration	ICV recoveries must be within 15% of the predicted response	1) Repeat calibration verification 2) Recalibrate if ICV fails
		Continuing Calibration Verification (CCV)	Daily prior to sample analysis and at 10% of client samples	CCV recoveries must be within 15% of the predicted response	1) Evaluate system 2) Correct problems 3) Repeat test 4) Recalibrate if fails

Table A-2. Summary of Calibration Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:8020 Modified for BTEX and 8015 Modified for JP-4	Soil Gas BTEX and TPH	5-Point Calibration	Initial and as required by daily check	RSD for all RFs must be <20% if mean RF used for quant.	Repeat calibration or use a calibration curve for quant.
		Initial Calibration Verification (ICV)	After initial calibration	ICV recoveries must be within 15% of the predicted response	1) Repeat calibration verification 2) Recalibrate if ICV fails
		Continuing Calibration Verification (CCV)	Every 10 samples if % difference is >15%	CCV recoveries must be within the Method acceptance criteria	1) Evaluate system 2) Correct problems 3) Repeat test 4) Recalibrate if fails
SW-846:8015 Modified for TPH as Gasoline	TPH as Gasoline	5-Point Calibration	Initial and as required by daily check	RSD for all RFs must be <20%	Retune instrument Repeat calibration analysis
		Initial Calibration Verification (ICV)	After initial calibration	ICV recoveries must be within 15% of the predicted response	Repeat verification Repeat calibration if fails
		Continuing Calibration Verification (CCV)	Daily prior to sample analysis	CCV must be within 15% of predicted response	1) Evaluate system 2) Correct problem 3) Repeat test 4) Recalibrate if fails

Table A-2. Summary of Calibration Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:8015 Modified for TPH as Diesel Fuel	TPH as Diesel	5-Point Calibration	Initial and as required by daily check	RSD for all RFs must be <20%	Retune instrument Repeat calibration analysis
		Initial Calibration Verification (ICV)	After initial calibration	ICV recoveries must be within 15% of the predicted response	Repeat calibration
		Continuing Calibration Verification (CCV)	Daily prior to sample analysis	CCV must be within 15% of predicted response	1) Evaluate system 2) Correct problems 3) Repeat test 4) Recalibrate if fails
EPA;365.4	Total Phosphorus	Calibration using eight standards	Daily	Refer to EPA 365.4	Reprepare samples and standards and reanalyze.
EPA;351.2	Total Kjehldahl Nitrogen	Calibration using two standards	Daily	Follow instrument manual	Repeat calibration
EPA;310.1	Alkalinity	Standardization using carbonate	Daily	Refer to EPA 310.1	Reprepare titrant
SW-846:9040 SW-846:9045A	pH	Calibration Using Two Standard Buffer Solutions	Daily	Follow instrument manual	Repeat calibration

Table A-2. Summary of Calibration Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:1010	Flashpoint	Calibration with xylenes	Daily	Refer to Method 1010	Repeat Calibration
EPA;413.1	Oil and Grease	Check balance calibration	Daily	Follow laboratory SOP	Recalibrate balance
ASTM D2216	Soil Moisture	Check balance calibration	Daily	Follow laboratory SOP	Recalibrate balance

EPA = Environmental Protection Agency
BTEX = Benzene, Toluene, Ethylbenzene, and Xylenes
TPH = Total Petroleum Hydrocarbons
AA = Atomic Absorption
DPT = Dichloro-diphenyl-trichloroethane
RF = Response Factor
RSD = Relative Standard Deviation
CCC = Calibration Check Compound
SPCC = System Performance Check Compound
PPB = Parts per Billion
TPH = Total Petroleum Hydrocarbons
BTEX = Benzene, Toluene, Ethylbenzene, and Xylenes
TRPH = Total Recoverable Petroleum Hydrocarbons
SW = Solid Waste
ICPES = Inductively Emission Spectroscopy Coupled Plasma
BFB = 4-Bromofluorobenzene
DFTPP = Decafluorotriphenylphosphine
RPD = Relative Percent Difference
RL = Reporting Limit
CCV = Continuing Calibration Verification
SOP = Standard Operating Procedure

Table A-3. Summary of Internal Quality Control Procedures

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
EPA:418.1	TRPH	Method Blank	1 per batch	<RL	Used to assess analytical contamination.
		Matrix Spike Duplicate	5%	66-136% Recovery	1) Run check sample (QCCS). 2) Correct problem 3) Flag data
		QA Duplicate Sample (USACE)	0 (not part of USACE work scope)	None	Will be used to determine precision
		Field Equipment Blank	0 (not part of USACE work scope)	None	Will be used to determine sources of contamination.
		Field Duplicate sample	0 (not part of USACE work scope)	None	Used to assess sampling/analytical variability.
SW-846:6010A	Metals (ICEPS)	Laboratory QC check sample analysis (QCCS)	1 per digestion batch ≤ 20 samples	Measured value within ± 20% of true value for element of interest	Repeat calibration
		Method blank	1 per digestion batch ≤ 20 samples	All analytes <MRL	1) Reanalyze. 2) Recalibrate. 3) Reanalyze 4) Redigest samples if reanalysis fails.
		Calibration blank	10%	All analytes <MRL	1) Rerun 2) Clean system 3) Reanalyze sample 4) Redigest samples if reanalysis fails.
		Calibration Check	10%	Measured value within ± 20% of true value for element of interest	Repeat calibration
		Matrix spike analysis	5%	80-120% Recovery	1) Analyze Method spike (or QCCS). 2) If method spike is ok, flag data. 3) If method spike not ok, see lab supervisor and reanalyze samples.

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:6010A (Continued)	Metals (ICEPS)	Matrix Spike Duplicate	5%	Relative percent difference ≤ 20% and 80-120% recovery	1) Analyze Method spike (or QCCS). 2) If method spike is ok, flag data. 3) If method spike not ok, see lab supervisor and reanalyze samples.
		ICPES interference check	Run at beginning and end of daily run	80-120% of true value for EPA check sample elements	1) Repeat calibration 2) See lab manager
		ICP linear range check	Quarterly	Measured value within ± 5% of expected value	Tests upper limit of ICP linear range.
		QA duplicate sample (USACEb)	0 (not part of USACE work scope)	None	Used to quantitate analytical variability.
		Field Duplicate field sample	0 (not part of USACE work scope)	None	Determine sampling analytical variability.
		Equipment Blanks	0 (not part of USACE work scope)	None	Used to determine sources of contamination.
SW-846:8270A	Semi-volatile Organic Compounds	Laboratory Check of mass spectral ion intensities using DFTPP	Daily prior to sample analysis	Refer to method	Retune instrument Repeat DFTPP analysis
		Quality Control Check Sample (QCCS)	5%	See Table A-4	1) Evaluate system, correct as needed. 2) Recalculate data or reanalyze extract. 3) If QCCS still fails, reextract and reanalyze QCCS and all samples in batch.
		System performance check	Every 12 hours	Minimum average response factor 0.050	1) Evaluate system 2) Repeat calibration.

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:8270A (Continued)	Semi-volatile Organic Compounds	Surrogate spikes	Every sample	See Table A-6	1) Evaluate system. 2) Recalculate data and/or reanalyze extract. 3) Analyze QCCS, if QCCS fails, reextract and reanalyze samples, or 4) Flag data and report analysis and re analysis results.
		Method Blank	Daily prior to sample analysis	<RL	1) Run solvent blank. 2) Evaluate system.
		Matrix spike	5%	See Table A-5	1) Run check sample (QCCS). 2) Correct problem 3) If QCCS fails, reanalyze samples. 4) Flag data if QCCS passes.
		Matrix Spike Duplicate	5%	See Table A-5	1) Run check sample (QCCS). 2) Correct problem 3) If QCCS fails, reanalyze samples. 4) Flag data if QCCS passes.
		QA duplicate sample (USACEb)	0	None	Used to quantitate analytical variability.
		Field Equipment blank	0	None	Will be used to determine sources of contamination.
		Duplicate field sample	0	None	Will be used to determine analytical variability.
SW-846:8240A	Volatile Organic Compounds	Laboratory Check of mass spectral ion intensities using BFB	Daily prior to sample analysis and/or every 12 hours	Method 8240A Table 3	1) Retune instrument 2) Repeat BFB analysis

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:8240A (Continued)	Volatile Organic Compounds	System performance check	Every 12 hours	RF ≥ 0.300 (0.250 for bromoform)	1) Evaluate system 2) Repeat calibration
		Surrogate spikes	Every sample	See Table A-6	1) Evaluate system 2) Recalculate data and/or reanalyze extract. 3) Reanalyze sample, or 4) Flag data and report analysis and reanalysis results.
		Method blank	Daily prior to analyses and/or every 12 hours	<RL except for acetone, MEK, or methylene chloride which may be 5 x RL	1) Run solvent blank 2) Reanalyze blank and samples
		Matrix spike	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		Matrix spike duplicate	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		QA duplicate sample (USACEb)	0	1 per site/matrix	Used to quantitate analytical variability.

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:8240A (Continued)	Volatile Organic Compounds (Continued)	Field Duplicate field samples	0	None	Used to determine sampling/analytical variability.
		Equipment blank	0	None	Will be used to determine sources of contamination.
		Trip blank	0	None	Will be used to determine potential sources of contamination.
SW-846:8020, Modified	BTEX Volatile Organic Compounds	Surrogate spikes	Every sample	See Table A-6	1) Evaluate system 2) Recalculate data and/or reanalyze extract. 3) Reanalyze sample, or 4) Flag data and report analysis and reanalysis results.
		Method blank	Daily prior to sample analyses	<RL	1) Run solvent blank (If methanol extracts) 2) Reanalyze blank and samples
		Matrix spike	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		Matrix spike duplicate	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		QA duplicate sample (USACEb)	0 (not part of USACE work scope)	None	Used to quantitate analytical variability.

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:8020, Modified (Continued)	BTEX Volatile Organic Compounds	Field Duplicate field samples	0 (not part of USACE work scope)	None	Used to determine sampling/analytical variability.
		Equipment blank	0 (not part of USACE work scope)	None	Will be used to determine sources of contamination.
		Trip blank	0 (not part of USACE work scope)	None	Will be used to determine potential sources of contamination.
SW-846 8010/8020	Volatile Organic Compounds	Daily Check Standard	Daily	All components must meet criteria set in SW-846, Table 3 for each compound (Table A-3)	1. Rerun Standard 2. Recalibrate
		Continuing Standard	Every 10th Sample	Must pass criteria set in SW-846m Table 3.	Stop Analysis; 1. Rerun standard 2. Recalibrate
		Surrogate	Each Sample	See Table A-6.	Repeat Analysis
		Internal Standard	Each Sample	50% - 200%	Repeat Analysis
		Method Blanks	Daily	<RL, except (MEK; Acetone; & MeC12)	Rerun Blank, stop analyses until criteria met.
SW-846:8080	Pesticides & PCBs	Surrogate spikes	Every sample	See Table A-6	1) Evaluate system 2) Recalculate data and/or reanalyze extract. 3) Reanalyze sample, or 4) Flag data and report analysis and reanalysis results.
		Method blank	Daily prior to analyses	<RL	1) Run solvent blank 2) Reanalyze blank and samples

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:8150A (Continued)	Chlorinated Herbicides	Matrix spike	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		Matrix spike duplicate	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		QA duplicate sample (USACEb)	0	None	Used to quantitate analytical variability.
		Field Duplicate field samples	0	None	Used to determine sampling/analytical variability.
		Equipment blank	0	None	Will be used to determine sources of contamination.
		Trip blank	0	None	Will be used to determine potential sources of contamination.
Modified SW-846:8015 Extraction 5030A	TPH as Gasoline	Surrogate spikes	Every sample	See Table A-6	1) Evaluate system 2) Recalculate data and/or reanalyze extract. 3) Reanalyze sample, or 4) Flag data and report analysis and reanalysis results.
		Method blank	Daily prior to analyses and/or every 12 hours	<MRL except for acetone, MEK, or methylene chloride which may be 5 x MRL	1) Run solvent blank 2) Reanalyze blank and samples

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
Modified SW-846:8015 Extraction 5030A (Continued)	TPH as Gasoline	Matrix spike	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		Matrix spike duplicate	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		QA duplicate sample (USACEb)	10%	None	Used to quantitate analytical variability.
		Field Duplicate field samples	0	None	Used to determine sampling/analytical variability.
		Equipment blank	0	None	Will be used to determine sources of contamination.
		Trip blank	0	None	Will be used to determine potential sources of contamination.
Modified SW-846:8015 Extraction 3010A/3550	TPH as Diesel Fuel	Surrogate spikes	Every sample	See Table A-6	1) Evaluate system 2) Recalculate data and/or reanalyze extract. 3) Reanalyze sample, or 4) Flag data and report analysis and reanalysis results.
		Method blank	Daily prior to analyses	<RL	1) Run solvent blank 2) Reanalyze blank and samples

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:8015 Extraction 3010A/3550 (Continued)	TPH as Diesel Fuel	Matrix spike	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		Matrix spike duplicate	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		QA duplicate sample (USACEb)	0	None	Used to quantitate analytical variability.
		Field Duplicate field samples	0	None	Used to determine sampling/analytical variability.
		Equipment blank	0	None	Will be used to determine sources of contamination.
		Trip blank	0	None	Will be used to determine potential sources of contamination.
SW-846:8020 Modified for BTEX and 8015 Modified for JP-4	Soil Gas BTEX and TPH JP-4	Surrogate spikes	Every sample	See Table A-6	1) Evaluate system 2) Recalculate data and/or reanalyze extract. 3) Reanalyze sample, or 4) Flag data and report analysis and reanalysis results.
		Method blank	One per batch of 20 samples or daily prior to analyses whichever is more frequent	<RL	1) Run solvent blank 2) Reanalyze blank and samples

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:8020 Modified for BTEX and 8015 Modified for JP-4 (Continued)	Soil Gas BTEX and TPH JP-4	Matrix spike	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		Matrix spike duplicate	5%	See Table A-5	1) Run check samples (QCCS). 2) Correct problem. 3) If QCCS is ok: flag data. 4) If QCCS is not ok; reanalyze samples
		QA duplicate sample (USACEb)	0 (not part of USACE work scope)	None	Used to quantitate analytical variability.
		Field Duplicate field samples	0 (not part of USACE work scope)	None	Used to determine sampling/analytical variability.
		Equipment blank	0 (not part of USACE work scope)	None	Will be used to determine sources of contamination.
		Trip blank	0	None	Will be used to determine potential sources of contamination.
SW-846:7060 SW-846:7421 SW-846:7471 SW-846:7740 SW-846:7841	Metals (AA) Arsenic Lead Mercury Selenium Thallium	Laboratory QC check sample (QCCS)	per sample batch	Measured value within ± 20% of expected value	Repeat calibration
		Calibration Check Verification	10%	Measured value within ± 20% of expected value	Repeat calibration

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:7060 SW-846:7421 SW-846:7471 SW-846:7740 SW-846:7841 (Continued)	Metals (AA) Arsenic Lead Mercury Selenium Thallium	Calibration blank	10%	<MRL	1) Clean system 2) Reanalyze
		Preparation blank	10%	<MRL	1) Reanalyze 2) Clean system 3) Redigest and reanalyze
		Matrix Spike	5%	75-125% Recovery	1) Run check sample (QCCS). 2) Correct problem 3) if QCCS fails, reanalyze samples 4) If not, flag data
		Matrix Spike Duplicate	5%	Within 20% RPD and 75-125% Recovery	1) Run check sample (QCCS). 2) Correct problem 3) if QCCS fails, reanalyze samples 4) If not, flag data
		QA duplicate sample (USACEb)	0	None	Will be used to determine sampling.analytical variability.
		Field Duplicate sample	0	None	Determine sampling/analytical variability.
		Equipment Blank	0	None	Will be used to determine sources of contamination.

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
EPA;365.4 EPA;351.2 EPA;310.1	Total Phosphorus Total Kjehldahl Nitrogen Alkalinity	Laboratory QC Check Sample	5%	Measured value within ± 20% of expected value	Reprepare and reanalyze samples and standards
		Preparation blank	10%	<MRL	1) Reanalyze 2) Clean system 3) Reprepare and reanalyze
		Matrix Spike	5%	80-120% Recovery	1) Run check sample (QCCS). 2) Correct problem 3) if QCCS fails, reanalyze samples 4) If not, flag data
		Matrix Spike Duplicate Analysis	5%	Within 20% RPD and 80-120% Recovery	Analyze third time. If still out, stop, identify, and correct problem.
		QA duplicate sample (USACEb)	0 (not part of USACE work scope)	None	Used to quantitate analytical variability
		Field Duplicate sample	0 (not part of USACE work scope)	None	Used to assess sampling/analytical variability.
		Equipment Blank	0 (not part of USACE work scope)	None	Will be used to determine sources of contamination.

Table A-3. Summary of Internal Quality Control Procedures (Continued)

Analytical Method	Parameter	Quality Control Check	Frequency	Acceptance Criteria	Corrective Action
SW-846:9040 SW-846:9045A	pH	Laboratory QC Check Sample	5%	± 0.1 pH units	Recalibrate
		Duplicate Analysis	5%	RPD ≤ 15	Analyze third time. If still out, stop, identify, and correct problem.
		QA duplicate sample (USACEb)	0 (not part of USACE work scope)	None	Used to quantitate analytical variability
		Field Duplicate sample	0 (not part of USACE work scope)	None	Used to assess sampling/analytical variability.

a Frequencies for duplicate samples and field blanks are computed based on the total number of samples taken for the number of analyses specified in the final specifications.

b USACE required QA duplicate samples to be analyzed by USACE Missouri River Division (MRD) Laboratory.

QCCS = Quality Control Check Sample
TRPH = Total Recoverable Petroleum Hydrocarbons
TPH = Total Petroleum Hydrocarbons
RF = Response Factor
RPD = Relative Percent Difference
RL = Reporting Limit
QA = Quality Assurance
MRL = Method Reporting Limit
ICEPS = Inductively Coupled Plasma Emission
AA = Atomic Absorption
BFB = 4-Bromofluorobenzene
DFTBB = Decafluorotriphenylposphine
MEK = 2 Butanone
BTEX = Benzene, Toluene, Ethylbenzene, and Xylenes

Table A-4. Summary of Tolerance Limits for Laboratory Control Samples (LCS)

Analyte	% Recovery	
	Water	Soil
METHOD E418.1		
Total Recoverable Petroleum Hydrocarbons	78-122	77-120
METHOD E413.1		
Oil and Grease	40-140	70-130
METHOD Mod. SW8015 TPH as Diesel & Hydrocarbon Screen		
TPH as Diesel	16-128	48.2-107
METHOD SW6010A		
Aluminum	80-120	80 -120
Antimony	80-120	80-120
Arsenic	80-120	80-120
Barium	80-120	80-120
Beryllium	80-120	80-120
Cadmium	80-120	80-120
Calcium	80-120	80-120
Chromium	80-120	80-120
Cobalt	80-120	80-120
Copper	80-120	80-120
Iron	80-120	80-120
Lead	80-120	80-120
Magnesium	80-120	80-120
Manganese	80-120	80-120
Nickel	80-120	80-120
Potassium	80-120	80-120
Selenium	80-120	80-120
Silver	80-120	80-120
Sodium	80-120	80-120
Thallium	80-120	80-120
Vanadium	80-120	80-120
Zinc	80-120	80-120
METHOD SW7060A		
Arsenic	80-120	80-120

Table A-4. Summary of Tolerance Limits for Laboratory Control Samples (LCS) (Continued)

Analyte	% Recovery	
	Water	Soil
METHOD SW7421		
Lead	80-120	80-120
METHODS SW7470 AND SW7471		
Mercury	80-120	80-120
METHOD SW7740		
Selenium	80-120	80-120
METHOD SW7841		
Thallium	80-120	80-120
METHOD SW8240A		
1,1-Dichloroethane	59-155	59-155
1,1-Dichloroethene	59-172	59-172
1,1,1-Trichloroethane	52-162	52-162
1,1,2-Trichloroethane	52-150	52-150
1,1,2,2-Tetrachloroethane	46-157	46-157
1,2-Dichloroethane	49-155	49-155
1,2-dichloropropane	10-210	10-210
Benzene	37-151	37-151
Bromodichloromethane	35-155	35-155
Bromomethane	10-242	10-242
Carbon Tetrachloride	70-140	70-140
Chlorobenzene	37-160	37-160
Chloroform	51-138	51-138
Chloromethane	10-273	10-273
cis-1,3-Dichloropropene	10-227	10-227
Dibromochloromethane	53-149	53-149
Ethyl benzene	37-162	37-162
Methylene chloride	10-221	10-221
Tetrachloroethene	64-148	64-148
Toluene	47-150	47-150
trans-1,2-Dichloroethene	54-156	54-156

Table A-4. Summary of Tolerance Limits for Laboratory Control Samples (LCS) (Continued)

Analyte	% Recovery	
	Water	Soil
trans-1,3-Dichloropropene	17-183	17-183
Tribromomethane (bromoform)	45-169	45-169
Trichlofluoromethane	17-181	17-181
Trichloroethene	71-157	71-157
Vinyl chloride	10-251	10-251
METHOD Mod. SW8020 BTEX and Mod. SW 8015 TPH as Gasoline		
Benzene	67-110	67-122
Toluene	68-115	66-126
Ethylbenzene	65-120	63-138
Xylenes (Total)	62-119	61-137
METHOD Mod. SW8020 BTEX and Mod. SW 8015 TPH as JP-4		
Benzene	--	39-150 (Gas)
Toluene	--	46-148 (Gas)
Ethylbenzene	--	32-160 (Gas)
Xylenes (Total)	--	32-160 (Gas)
TPH as JP-4 (gasoline values)	--	50-150 (Gas)
METHOD 8010/8020		
1,1-Dichloroethane	84-116	84-116
1,1-Dichloroethene	63-137	63-137
1,1,1-Trichloroethane	71-129	71-129
1,1,2-Trichloroethane	79-122	79-122
1,1,2,2-Tetrachloroethane	49-151	49-151
1,2-Dichloroethane	72-129	72-129
1,2-dichloropropane	72-126	72-126
Benzene	77-123	77-123
Bromodichloromethane	76-124	76-124
Bromomethane	59-142	59-142
Carbon Tetrachloride	69-132	69-132
Chlorobenzene	72-128	72-128
Chloroform	75-125	75-125

Table A-4. Summary of Tolerance Limits for Laboratory Control Samples (LCS) (Continued)

Analyte	% Recovery	
	Water	Soil
Chloromethane	60-141	60-141
cis-1,3-Dichloropropane	64-136	64-136
Dibromochloromethane	66-155	66-155
Ethyl benzene	63-137	63-137
Methylene chloride	78-123	78-123
Tetrachloroethane	70-130	70-130
Toluene	78-122	78-122
trans-1,2-dichloroethene	64-136	64-136
Tribromomethane (bromoform)	74-123	74-123
Trichlofluoromethane	67-134	67-134
Trichloroethane	77-123	77-123
Vinyl chloride	69-132	69-132
2-chloroethyl vinyl ether	60-140	60-140
Chloroethane	77-123	77-123
xylene	85-115	85-115
1,2-dichlorobenzene	70-130	70-130
1,3-dichlorobenzene	50-151	50-151
1,4-dichlorobenzene	70-131	70-131
METHOD SW8270A		
Phenol	12-110	26-90
2-Chlorophenol	27-123	25-102
1,4-Dichlorobenzene	36-97	28-104
N-Nitroso-di-n-propylamine	41-116	41-126
1,2,4-Trichlorobenzene	39-98	38-107
4,Chloro-3-methylphenol	23-97	26-103
Acenaphthene	46-118	31-137
4-Nitrophenol	10-80	11-114
2,4-Dinitrotoluene	24-96	28-89
Pentachlorophenol	9-103	17-109
Pyrene	26-127	35-142
METHOD SW 8080		
Aldrin	40-120	34-132

Table A-4. Summary of Tolerance Limits for Laboratory Control Samples (LCS) (Continued)

Analyte	% Recovery	
	Water	Soil
α-BHC	37-134	37-134
β-BHC	17-147	17-147
δ-BHC	19-140	19-140
γ-BHC	46-127	46-127
4,4'-DDD	31-141	31-141
4,4'-DDE	30-145	30-145
4,4'-DDT	38-127	23-134
Dieldrin	52-126	31-134
Endosulfan I	45-153	45-153
Endosulfan II	10-202	10-202
Endosulfan Sulfate	26-144	26-144
Endrin	56-121	42-139
Endrin Aldehyde	20-200	10-200
Heptachlor	40-131	35-130
Heptachlor Epoxide	37-142	37-142
METHOD SW8080 PCB's		
PCB 1260	10-127	10-127
METHOD SW 8150A		
2,4-D	20-160	20-160
2,4,5-TP (Silvex)	20-160	20-160
GENERAL		
Alkalinity E310.1	80-120	80-120
Kjeldahl Nitrogen (Total) E351.2	80-120	80-120
Phosphorous E365.4	80-120	80-120
pH SW9040 /SW9045A	0.1 pH Unit	0.1 pH Unit
TCLP-METHOD SW6010A & SW7470		
Arsenic	N/A	80-120
Barium	N/A	80-120
Cadmium	N/A	80-120
Calcium	N/A	80-120
Chromium	N/A	80-120

Table A-4. Summary of Tolerance Limits for Laboratory Control Samples (LCS) (Continued)

Analyte	% Recovery	
	Water	Soil
Mercury (SW7470)	N/A	80-120
Lead	N/A	80-120
Selenium	N/A	80-120
Silver	N/A	80-120
TCLP - METHOD SW8240A		
Benzene	N/A	76-127
2-Butanone	N/A	28-180
Carbon Tetrachloride	N/A	70-140
Chlorobenzene	N/A	75-130
Chloroform	N/A	51-138
1,4-Dichlorobenzene	N/A	18-190
1,2-Dichloroethane	N/A	49-155
1,1-Dichloroethene	N/A	61-145
Trichloroethene	N/A	71-120
Tetrachloroethene	N/A	64-148
Vinyl Chloride	N/A	10-251
TCLP - METHOD SW8270A		
Pyridine	N/A	10-150
1,4-Dichlorobenzene	N/A	36-97
2-Methylphenol	N/A	32-119
3,4-Methylphenol	N/A	32-119
Hexachloroethane	N/A	40-113
Nitrobenzene	N/A	35-180
Hexachlorobutadiene	N/A	24-116
2,4,6-Trichlorophenol	N/A	37-144
2,4,5-Trichlorophenol	N/A	37-144
2,4-Dinitrotoluene	N/A	24-96
Hexachlorobenzene	N/A	10-152
Pentachlorophenol	N/A	10-103
TCLP - METHOD SW8080		
gamma-BHC (Lindane)	N/A	46-127
Heptachlor	N/A	35-130

Table A-4. Summary of Tolerance Limits for Laboratory Control Samples (LCS) (Continued)

Analyte	% Recovery	
	Water	Soil
Heptachlor Epoxide	N/A	37-142
Aldrin	N/A	34-132
Dieldrin	N/A	31-134
Endrin	N/A	42-139
4,4'- DDT	N/A	23--134
TCLP - METHOD SW8150A		
2,4-D	N/A	20-160
2,4,5-TP (Silvex)	N/A	20-160

LCS = Laboratory Control Samples
TPH = Total Petroleum Hydrocarbons
BTEX = Benzene, Toluene, Ethylbenzene, and Xylenes
N/A = Not Applicable
(Gas) = Soil Gas Sample

Table A-5. Summary of Tolerance Limits for Matrix Spike Analyses

Analyte	Water Spike Concent Analyte (ug/l)	Soil Spike Concent (mg/kg)	% Recovery		Precision (RPD)	
			Water	Soil	Water	Soil
METHOD E418.1						
Total Recoverable Petroleum Hydrocarbons	5,000	3	66-136	42-141	70	50
METHOD E413.1						
Oil and Grease	30,000	1,500	40-140	70-130	50	50
METHOD Mod. SW 8015 TPH as Diesel and Hydrocarbon Screen						
TPH as Diesel	2,000	66.7	16-126	48-107	67.4	26.8
METHOD SW6010A						
Aluminum	10,000	1,000	80-120	80-120	20	20
Antimony	2,000	200	80-120	80-120	20	20
Arsenic	10,000	1,000	80-120	80-120	20	20
Barium	100	10	80-120	80-120	20	20
Beryllium	500	50	80-120	80-120	20	20
Cadmium	10,020	1,002	80-120	80-120	20	20
Calcium	200	20	80-120	80-120	20	20
Chromium	2,005	200.5	80-120	80-120	20	20
Cobalt	2,000	200	80-120	80-120	20	20
Copper	10,000	1,000	80-120	80-120	20	20
Iron	2,000	200	80-120	80-120	20	20
Lead	10,000	1,000	80-120	80-120	20	20
Magnesium	5,000	500	80-120	80-120	20	20
Manganese	5,000	500	80-120	80-120	20	20
Nickel	20,000	2,000	80-120	80-120	20	20
Potassium	1,000	100	80-120	80-120	20	20
Selenium	1,000	100	80-120	80-120	20	20
Silver	10,010	1,001	80-120	80-120	20	20
Sodium	2,000	200	80-120	80-120	20	20
Thallium	2,000	200	80-120	80-120	20	20
Vanadium	2,000	200	80-120	80-120	20	20
Zinc	5,005	500.5	80-120	80-120	20	20

Table A-5. Summary of Surrogate Spike Tolerance Limits (Continued)

Analyte	Water Spike Concent Analyte (ug/l)	Soil Spike Concent (ug/kg)	% Recovery		Precision (RPD)	
			Water	Soil	Water	Soil
METHOD SW7060						
Arsenic	40	4,000	75-125	75-125	20	20
METHOD SW7421						
Lead	20	2,000	75-125	75-125	20	20
METHODS SW7470 AND SW7471						
Mercury	40.0	4,000	75-125	75-125	20	20
METHOD SW7740						
Selenium	1	2	75-125	75-125	20	20
METHOD SW7841						
Thallium	20.0	2,000	75-125	75-125	20	20
METHOD Mod. SW8020 BTEX and Mod. SW8015 TPH-as-Gasoline (Fixed Laboratory)						
Benzene	20	5,000	67-110	67-122	23.9	28.3
Toluene	20	5,000	68-115	66-126	27.2	30.0
Ethylbenzene	20	5,000	65-120	63-138	21.6	30.0
Xylenes (Total)	20	5,000	62-119	61-137	22.0	30.0
METHOD SW8240A (Fixed Laboratory)						
Benzene	50	50	76-127	66-142	11	21
Chlorobenzene	50	50	75-130	60-133	13	21
1,1-Dichloroethane	50	50	61-145	59-172	14	22
Toluene	50	50	71-120	62-137	14	24
Trichloroethene	50	50	76-125	59-139	13	21
METHOD Mod. SW8020 BTEX and Mod. SW8015 TPH-as-Gasoline (Soil Gas)						
Benzene	N/A	--	N/A	39-150 (Gas)	N/A	20 (Gas)
Toluene	N/A	--	N/A	46-148 (Gas)	N/A	20 (Gas)
Ethylbenzene	N/A	--	N/A	32-160 (Gas)	N/A	20 (Gas)
Xylenes (Total)	N/A	--	N/A	32-160 (Gas)	N/A	20 (Gas)
TPH as JP-4 (Gasoline values)	N/A	--	N/A	50-150 (Gas)	N/A	20 (Gas)

Table A-5. Summary of Surrogate Spike Tolerance Limits (Continued)

Analyte	Water Spike Concent Analyte (ug/l)	Soil Spike Concent (ug/kg)	% Recovery		Precision (RPD)	
			Water	Soil	Water	Soil
METHOD Mod. SW8020 BTEX and Mod. SW8015 TPH-as-Gasoline (Mobile Laboratory)						
Benzene	20	1,000	67-110	67-122	23.9	28.3
Toluene	20	1,000	68-115	66-126	27.2	30.0
Ethylbenzene	20	1,000	65-120	63-138	21.6	30.0
Xylenes (Total)	20	1,000	62-119	61-137	22.0	30.0
METHOD SW8240A (Mobile Laboratory)						
Benzene	50	2,500	76-127	66-142	11	21
Chlorobenzene	50	2,500	75-130	60-133	13	21
1,1-Dichloroethane	50	2,500	61-145	59-172	14	22
Toluene	50	2,500	71-120	62-137	14	24
Trichloroethene	50	2,500	76-125	59-139	13	21
METHOD 8010/8020 (Mobile Laboratory)						
1,1-Dichloroethane	20	1,000	28-167	28-167	20	20
Benzene	20	1,000	39-150	39-150	20	20
Chlorobenzene	20	1,000	38-150	38-150	20	20
Chloroform	20	1,000	49-133	49-133	20	20
Tetrachloroethene	20	1,000	26-162	26-162	20	20
Toluene	20	1,000	46-148	46-148	20	20
Trichloroethene	20	1,000	35-146	35-146	20	20
METHOD SW8080						
gamma-BHC (Lindane)	0.5	16.7	56-123	46-127	15	35.4
Heptachlor	0.5	16.7	40-131	35-130	20	21.9
Aldrin	0.5	16.7	40-120	34-132	22	30.4
Dieldrin	0.5	16.7	52-126	31-134	18	26.9
Endrin	0.5	16.7	56-121	42-139	21	31.8
4,4'- DDT	0.5	16.7	38-127	23-134	27	35.4
METHOD SW8080 PCB's						
PCB 1260	1	33.4	10-127	10-127	26.1	26.1
METHOD SW 8150A						
2,4-D	0.75	25	20-160	20-160	40	40
2,4,5-TP (Silvex)	0.75	8.3	20-160	20-160	40	40

Table A-5. Summary of Surrogate Spike Tolerance Limits (Continued)

Analyte	Water Spike Concent Analyte (ug/l)	Soil Spike Concent (ug/kg)	% Recovery		Precision (RPD)	
			Water	Soil	Water	Soil
GENERAL						
Alkalinity E310.1	N/A	N/A	N/A	N/A	20	20
Kjeldahl Nitrogen (Total) E351.2	1,000	20,000	80-120	80-120	20	20
Phosphorous E 365.4	2,500	25,000	80-120	80-120	20	20
pH SW9040/SW9045A	N/A	NA	N/A	N/A	0.2 pH Unit	0.2 pH Unit
METHOD SW8270A						
Phenol	200	6,700	12-110	26-90	42	35
2-Chlorophenol	200	6,700	27-123	25-102	40	50
1,4-Dichlorobenzene	100	3,300	36-97	28-104	28	27
N-Nitrosodi-n-propylamine	100	3,300	41-116	41-126	38	38
1,2,4-Trichlorobenzene	100	3,300	39-98	38-107	28	23
4-Chloro-3-Methylphenol	200	6,700	23-97	26-103	42	33
Acenaphthene	100	3,300	46-118	31-137	31	19
4-Nitrophenol	200	6,700	10-80	11-114	50	50
2,4-Dinitrotoluene	100	3,300	24-96	28-89	38	47
Pentachlorophenol	200	6,700	9-103	17-103	50	47
Pyrene	100	3,300	26-127	35-142	31	36

Analyte	TCLP Spike Concent (mg/l)	% Recovery		Precision (RPD)	
		Water	Soil	Water	Soil
TCLP-METHOD SW6010A & SW7470					
Arsenic	8.0	N/A	80-120	N/A	20
Barium	40	N/A	80-120	N/A	20
Cadmium	2.0	N/A	80-120	N/A	20
Chromium	0.8	N/A	80-120	N/A	20
Mercury (SW7470)	0.004	N/A	80-120	N/A	20
Lead	8.0	N/A	80-120	N/A	20
Selenium	4.0	N/A	80-120	N/A	20
Silver	4.0	N/A	80-120	N/A	20

Table A-5. Summary of Surrogate Spike Tolerance Limits (Continued)

Analyte	TCLP Spike Concent (mg/l)	% Recovery		Precision (RPD)	
		Water	Soil	Water	Soil
TCLP - METHOD SW8240A					
Benzene	0.1	N/A	76-127	N/A	11
2-Butanone	0.1	N/A	28-180	N/A	25
Carbon Tetrachloride	0.1	N/A	70-140	N/A	11.3
Chlorobenzene	0.1	N/A	75-130	N/A	13
Chloroform	0.1	N/A	51-138	N/A	18.2
1,4-Dichlorobenzene	0.1	N/A	18-190	N/A	28.8
1,2-Dichloroethane	0.1	N/A	49-155	N/A	20.6
1,1-Dichloroethene	0.1	N/A	61-145	N/A	14
Trichloroethene	0.1	N/A	71-120	N/A	14
Tetrachloroethene	0.1	N/A	64-148	N/A	15.6
Vinyl Chloride	0.1	N/A	10-251	N/A	65
TCLP - METHOD SW8080					
gamma-BHC (Lindane)		N/A	46-127	N/A	10.6
Heptachlor	1.67	N/A	35-130	N/A	14.1
Heptachlor Epoxide	1.67	N/A	37-142	N/A	15.3
Aldrin	1.67	N/A	34-132	N/A	15.6
Dieldrin	1.67	N/A	31-134	N/A	12.7
Endrin	1.67	N/A	42-139	N/A	14.8
4,4'- DDT	1.67	N/A	23-134	N/A	19.1
TCLP-METHOD SW8150A					
2,4-D	0.0025	N/A	20-160	N/A	40
2,4,5-TP (Silvex)		N/A	20-160	N/A	40
TCLP - METHOD SW8270A					
Pyridine	0.33	N/A	10-150	N/A	50
1,4-Dichlorobenzene	0.33	N/A	36-97	N/A	27
2-Methylphenol	0.33	N/A	32-119	N/A	34
3,4-Methylphenol	0.33	N/A	32-119	N/A	34
Hexachloroethane	0.33	N/A	40-113	N/A	26
Nitrobenzene	0.33	N/A	35-180	N/A	39
Hexachlorobutadiene	0.33	N/A	24-116	N/A	38
2,4,6-Trichlorophenol	0.33	N/A	37-144	N/A	34

Table A-5. Summary of Surrogate Spike Tolerance Limits (Continued)

Analyte	TCLP Spike Concent (mg/l)	% Recovery		Precision (RPD)	
		Water	Soil	Water	Soil
2,4,5-Trichlorophenol	0.33	N/A	37-144	N/A	34
2,4-Dinitrotoluene	0.33	N/A	24-96	N/A	47
Hexachlorobenzene	0.33	N/A	10-152	N/A	60
Pentachlorophenol	0.33	N/A	10-103	N/A	47

N/A = Not Applicable
ug/l = Microgram per Liter
mg/l = Milligram per Liter
ug/kg = Microgram per Kilogram
mg/kg = Milligram per Kilogram
TPH = Total Petroleum Hydrocarbons
BTEX = Benzene, Toluene, Ethylbenzene, and Xylenes
RPD = Relative Percent Difference
SW = Solid Waste
TCLP = Toxicity Charactersistoc Leaching Procedure
(Gas) = Soil Gas Sample

Table A-6. Summary of Surrogate Spike Tolerance Limits

Surrogate Compound	Water (% Recovery)	Soil (% Recovery)
METHOD SW8020/8010		
a,a,a,-Trifluorotoluene	N/A	N/A
1,4-Bromofluorobenzene	43-133	46-133
Bromochloromethane	68-132	54-129
METHOD SW8240		
Toluene-d_8	88-110	81-117
4-Bromofluorobenzene	86-115	74-121
1,2-Dichloroethane-d_4	76-114	70-121
METHOD SW8270		
2-Fluorobiphenyl	43-116	30-115
2-Fluorophenol	21-100	25-121
2,4,6-Tribromophenol	10-123	19-122
Nitrobenzene-d_5	35-114	23-120
p-Terphenyl-d_{14}	33-141	18-137
Phenol-d_5	10-94	24-113
METHOD SW 8080		
2,4,5,6-Tetrachloro-meta-xylene	19.6-132	35.4-126
Dibutychlorendate	51.2-135	23.0-144
METHOD SW 8150		
Dichlorophenylacetic acid (DCPAA)	24-154	24-154
METHOD SW Mod. 8015 TPH as Diesel & Hydrocarbon Screens		
ortho-Terphenyl	43.3-126	21.5-128
METHOD SW Mod. 8020 BTEX and Mod. 8015 TPH as JP-4		
1,4-Bromofluorobenzene	N/A	46-133 (Gas)

N/A = Not Applicable
TPH = Total Petroleum Hydrocarbons
(Gas) = Soil Gas Sample

Table A-7. Laboratory Sample Container and Preservation Requirements

Sample Matrix	Reference Method	Analytical Parameter	Sample Containers Type[2]	Required Preservation[1]	Maximum Holding Times[3]
Soil Samples	EPA:310.1 (Mod.)	Alkalinity	b		14 day
	EPA:351.2 (Mod.)	Total Kjieldhal Nitrogen	b		28 days
	EPA:365.4	Phosophorus	b		28 days
	EPA:418.1	TRPH	b		14 days
	SW-846:BTEX 8020	Volatile Organics	a		14 days
	SW-846:6010A	Fe	b		6 months
	SW9045A	Ph	a		None
	ASTM:D-2216	Soil Moisture	b		None
Soil Gas	SW-846: 8020, 8015 (mod.)	BTEX and TPH as JP-4	e		72 hours

[1] - All samples will be cooled to at least 4°C immediately after collection.
[2] - All containers will have Teflon-lined lids. The container volume may vary pending laboratory-specific requirements.
[3] - The hold times for extraction and analysis are the same unless otherwise specified.

Sample containers:
a - 120 ml wide mouth glass jar with a teflon lined lid.
b - 250 ml wide mouth glass jar with a teflon lined lid.
c - 40 ml volatiles organics vial with a teflon lined lid.
d - 1 liter wide mouth amber glass bottle with a teflon lined lid.
e - 10-milliliter gas syringe

APPENDIX B -- FORMS

Daily Quality Control Report (DQCR)

Nonconformance Report (NCR)

Procedure Change Request Form (PCRF)

Information Request

Malfunction Report

_____
(FIRM NAME)

DAILY QUALITY CONTROL REPORT

Daily Report No.:_____ Date: _____
Contract No.:_____
Project Title & Location: _____
Weather: _____ Precipitation: _____ In.:___ Temp.:_____ Min.:_____ Max.:_

1. Contract/Subcontractors and Area of Responsibility:

NUMBER	TRADE	HOURS	EMPLOYER	LOCATION/DESCRIPTION WORK

2. Operating Plant or Equipment. (Not hand tools)

Plant/Equipment	Date of Arrival/ Departure	Date of Safety Check	Hours Used	Hours Idle	Hours Repair

3. Work Performed Today: (Indicate location and description of work performed by prime and/or subcontractors. When network analysis is used, identify work by NAS activity number).

4. Control Activities Performed:
Preparatory Inspections: (Identify feature of work and attached minutes).
Initial Inspections: (Identify feature of work and attach minutes).
Follow-Up Inspections: (List inspections performed, results of inspection compared to specification requirements, and corrective actions taken when deficiencies are noted).

5. Tests Performed and Test Results: (Identify test requirement by paragraph number in specifications and/or sheet number in plans).

6. Material Received: (Note inspection results and storage provided).

7. Submittals Reviewed:

(a) Submittal No.	(b) Spec/Plan Reference	(c) By Whom	(d) Action

8. Off-site Surveillance Activities, Including Action Taken:

9. Job Safety: (List items checked, results, instructions and corrective actions taken).

10. Remarks: (Instructions received or given. Conflicts(s) in Plans and/or specifications. Delays encountered.).

Contractor's Verification: On behalf of the Contractor, I certify this report is complete and correct, and all materials and equipment used and work performed during this reporting period are in compliance with the contract plans and specifications, to the best of my knowledge, except as may be noted above.

CQC System Manager Date

Nonconformance Report

EBASCO
Quality
Programs
Division

Client	NCR No.
Project	Date
Responsible Contractor	Drawing / Specification No.
Applicable Daily Report	

Description of Component

Name and Signature	Title and Company	Date

Recommended Disposition

Name and Signature	Title and Company	Date

Corrective Action

Required ☐ Not Required ☐

Review Proposed Action

Accepted ☐ Rejected ☐ Accepted with Comments ☐

Name and Signature	Title and Company	Date

Verification of Disposition

Required ☐ Not Required ☐

Name and Signature	Title and Company	Date

Inspector (Signature)	Date	Reviewed by	Date

HAFB Form No. 35
Rev.2 2.14.95 jb

PROCEDURE CHANGE REQUEST FORM

Page ___ of ___

Procedure No._____
Procedure Change Requested:_____

DESCRIPTION

1. Current Description: (Include SOP No., Page(s), Paragraph No., etc.)

_____
_____
_____
_____
_____
_____
_____
_____
_____

2. Recommended Change:

_____
_____
_____
_____
_____
_____
_____
_____
_____

3. Initiator Signature/Date: _____

4. QA Manager Signature/Date: _____

5. Responsible Project Manager: _____

6. Reason For Change:

_____
_____
_____
_____
_____
_____

RESOLUTION

7. Is change implemented? Yes: _____ No: _____
8. If yes, attach procedure and mark Procedure Change Notice.

APPROVAL

9. QA Manager Signature/Date: _____
10. Program Manager Signature/Date: _____

NOTE: All appropriate signatures/dates must be obtained prior to disposition.

INFORMATION REQUEST

IR #:_____ Distribution Copies To:_____
TO:_____ _____
FROM:_____ _____
DATE:_____ _____

Project Reference:_____ LAB Reference:_____

Information Required:

Support Documentation Required: ☐ Yes ☐ No

Date Information Required:_____

Response:

Follow-up Required: ☐ Yes ☐ No

Additional Comments:

Date Resolved:_____ Verified by:_____

MALFUNCTION REPORT

Malfunction Report Number_____

Malfunction Type_____
1 - QC Limits Exceeded
2 - Documentation
3 - Other (explain)

Urgency Level_____
1 - Required immediate attention
2 - Should be addressed within 7 days
3 - Requires written explanation within 14 days

Laboratory:_____ Reported to:_____

Location:_____ Position:_____

Contract:_____

Date/Time of Malfunction:_____ Date Reported:_____

Malfunction Reported by:_____

Matrix: ☐ Solid ☐ Water ☐ Air ☐ Other_____

Description of Problem:_____

_____

_____

Action:_____

_____

_____

_____

_____

Date/Time Resolved:_____ By Whom:_____

(Upon completion, send copies to distribution listed and return original to person who reported the malfunction).

Distribution: _____ _____ _____
_____ _____ _____
_____ _____ _____

APPENDIX C -- GEOTECHNICAL LABORATORY PROCEDURES

C-1 ASTM Standard D4318-93 Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index Soils

Designation: D 4318 – 93

Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[1]

This standard is issued under the fixed designation D 4318; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the liquid limit, plastic limit, and the plasticity index of soils as defined in Section 3.

1.1.1 Two procedures for preparing test specimens are provided as follows: *Wet preparation procedure*, as described in 10.1. *Dry preparation procedure*, as described in 10.2. The procedure to be used shall be specified by the requesting authority. If no procedure is specified, use the wet preparation procedure.

1.1.2 Two methods for determining the liquid limit are provided as follows: *Method A*, Multipoint test as described in Sections 11 and 12. *Method B*, One-point test as described in Sections 14 and 15. The method to be used shall be specified by the requesting authority. If no method is specified, use Method A.

1.1.3 The plastic limit test procedure is described in Sections 16, 17, and 18. The plastic limit test is performed on material prepared for the liquid limit test.

1.1.4 The procedure for calculating the plasticity index is given in Section 19.

1.2 The liquid limit and plastic limit of soils (along with the shrinkage limit) are often collectively referred to as the Atterberg limits. These limits distinguished the boundaries of the several consistency states of plastic soils.

1.3 The multipoint liquid limit method is generally more precise than the one-point method. It is recommended that the multipoint method be used in cases where results may be subject to dispute, or where greater precision is required.

1.4 Because the one-point method requires the operator to judge when the test specimen is approximately at its liquid limit, it is particularly not recommended for use by inexperienced operators.

1.5 The correlations on which the calculations of the one-point method are based may not be valid for certain soils, such as organic soils or soils from a marine environment. It is strongly recommended that the liquid limit of these soils be determined by the multipoint method.

1.6 The liquid and plastic limits of many soils that have been allowed to dry before testing may be considerably different from values obtained on undried samples. If the liquid and plastic limits of soils are used to correlate or estimate the engineering behavior of soils in their natural moist state, samples should not be permitted to dry before testing unless data on dried samples are specifically desired.

1.7 The composition and concentration of soluble salts in a soil affect the values of the liquid and plastic limits as well as the water content values of soils (see Method D 2216). Special consideration should therefore be given to soils from a marine environment or other sources where high soluble salt concentrations may be present. The degree to which the salts present in these soils are diluted or concentrated must be given careful consideration.

1.8 Since the tests described herein are performed only on that portion of a soil which passes the 425-μm (No. 40) sieve, the relative contribution of this portion of the soil to the properties of the sample as a whole must be considered when using these tests to evaluate properties of a soil.

1.9 The values stated in acceptable metric units are to be regarded as the standard. The values given in parentheses are for information only.

1.10 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Methods for Reducing Field Samples of Aggregate to Testing Size[3]

D 75 Practice for Sampling Aggregates[2]

D 420 Practice for Investigating and Sampling Soil and Rock for Engineering Purposes[2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

D 1241 Specification for Materials for Soil-Aggregate Subbase, Base, and Surface Courses[2]

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[2]

D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[2]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

D 3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes[3]

D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil and Rock Testing[3]

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[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved Nov. 15, 1993. Published January 1994. Originally published as D 4318 – 83. Last previous edition D 4318 – 83ε[1].

[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[2]

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions of terms in this test method are in accordance with Terminology D 653.

3.2 *Description of Terms Specific to This Standard:*

3.2.1 *Atterberg limits*—Originally, six "limits of consistency" of fine-grained soils were defined by Albert Atterberg: the upper limit of viscous flow, the liquid limit, the sticky limit, the cohesion limit, the plastic limit, and the shrinkage limit. In current engineering usage, the term usually refers only to the liquid limit, plastic limit, and in some references, the shrinkage limit.

3.2.2 *consistency*—the relative ease with which a soil can be deformed.

3.2.3 *liquid limit (LL)*—the water content, in percent, of a soil at the arbitrarily defined boundary between the liquid and plastic states. This water content is defined as the water content at which a pat of soil placed in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (½ in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of 2 shocks per second.

3.2.3.1 *Discussion*—The undrained shear strength of soil at the liquid limit is considered to be approximately 2 kPa (0.28 psi).

3.2.4 *plastic limit (PL)*—the water content, in percent, of a soil at the boundary between the plastic and brittle states. The water content at this boundary is the water content at which a soil can no longer be deformed by rolling into 3.2 mm (⅛ in.) in diameter threads without crumbling.

3.2.5 *plastic soil*—a soil which has a range of water content over which it exhibits plasticity and which will retain its shape on drying.

3.2.6 *plasticity index (PI)*—the range of water content over which a soil behaves plastically. Numerically, it is the difference between the liquid limit and the plastic limit.

3.2.7 *liquidity index*—the ratio, expressed as a percentage of (1) the natural water content of a soil minus its plastic limit, to (2) its plasticity index.

3.2.8 *activity number (A)*—the ratio of (1) the plasticity index of a soil to (2) the percent by weight of particles having an equivalent diameter smaller than 0.002 mm.

4. Summary of Test Method

4.1 The sample is processed to remove any material retained on a 425-µm (No. 40) sieve. The liquid limit is determined by performing trials in which a portion of the sample is spread in a brass cup, divided in two by a grooving tool, and then allowed to flow together from the shocks caused by repeatedly dropping the cup in a standard mechanical device. The multipoint liquid limit, Method A, requires three or more trials over a range of water contents to be performed and the data from the trials plotted or calculated to make a relationship from which the liquid limit is determined. The one-point liquid limit, Method B, uses the data from two trials at one water content multiplied by a correction factor to determine the liquid limit.

4.2 The plastic limit is determined by alternately pressing together and rolling into a 3.2-mm (⅛-in.) diameter thread a small portion of plastic soil until its water content is reduced to a point at which the thread crumbles and can no longer be pressed together and rerolled. The water content of the soil at this point is reported as the plastic limit.

4.3 The plasticity index is calculated as the difference between the liquid limit and the plastic limit.

5. Significance and Use

5.1 This test method is used as an integral part of several engineering classification systems to characterize the fine-grained fractions of soils (see Test Method D 2487 and Practice D 3282) and to specify the fine-grained fraction of construction materials (see Specification D 1241). The liquid limit, plastic limit, and plasticity index of soils are also used extensively, either individually or together, with other soil properties to correlate with engineering behavior such as compressibility, permeability, compactibility, shrink-swell, and shear strength.

5.2 The liquid and plastic limits of a soil can be used with the natural water content of the soil to express its relative consistency or liquidity index and can be used with the percentage finer than 2-µm size to determine its activity number.

5.3 These methods are sometimes used to evaluate the weathering characteristics of clay-shale materials. When subjected to repeated wetting and drying cycles, the liquid limits of these materials tend to increase. The amount of increase is considered to be a measure of a shale's susceptibility to weathering.

5.4 The liquid limit of a soil containing substantial amounts of organic matter decreases dramatically when the soil is oven-dried before testing. Comparison of the liquid limit of a sample before and after oven-drying can therefore be used as a qualitative measure of organic matter content of a soil.

6. Apparatus

6.1 *Liquid Limit Device*—A mechanical device consisting of a brass cup suspended from a carriage designed to control its drop onto a hard rubber base. Figure 1 shows the essential features and critical dimensions of the device. The device may be operated by either a hand crank or electric motor.

6.1.1 *Base*—A hard rubber base having a D Durometer hardness of 80 to 90, and a resilience such that an 8-mm (5/16-in.) diameter polished steel ball, when dropped from a height of 25 cm (9.84 in.) will have an average rebound of at least 80 % but no more than 90 %. Conduct resilience tests on the finished base with the feet attached. Details for measuring the resilience of the base are given in Appendix A.

6.1.2 *Rubber Feet*, supporting the base, designed to provide isolation of the base from the work surface, and having an A Durometer hardness no greater than 60 as measured on the finished feet attached to the base.

6.1.3 *Cup*, brass, with a weight, including cup hanger, of 185 to 215 g.

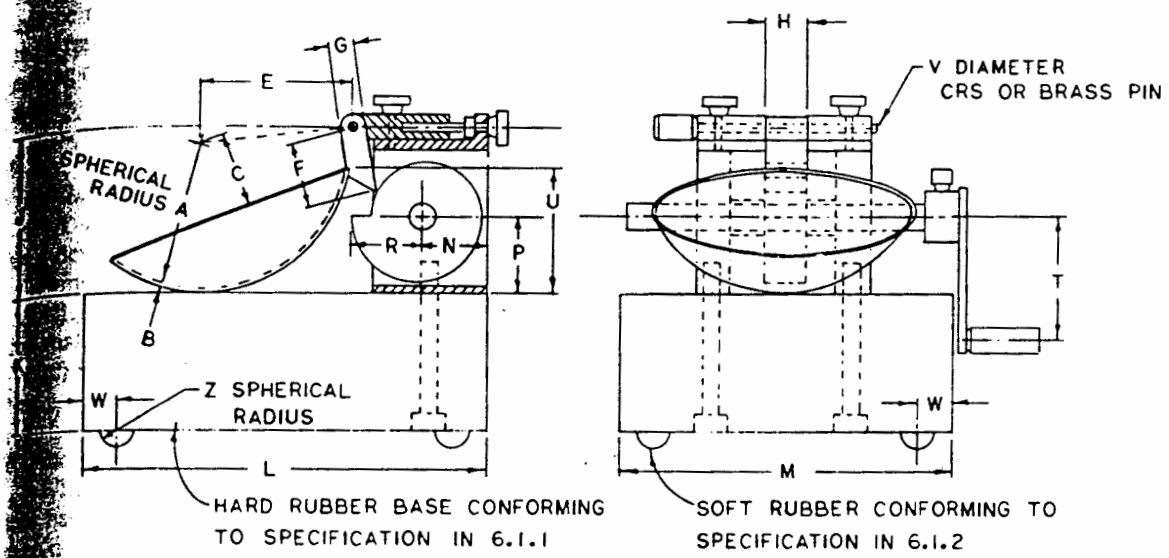
6.1.4 *Cam*—designed to raise the cup smoothly and continuously to its maximum height, over a distance of at least 180° of cam rotation, without developing an upward or downward velocity of the cup when the cam follower leaves

DIMENSIONS

LETTER	A Δ	B Δ	C Δ	E Δ	F	G	H	J Δ	K Δ	L Δ	M Δ
MM	54 ± 0.5	2 ± 0.1	27 ± 0.5	56 ± 2.0	32	10	16	60 ± 1.0	50 ± 2.0	150 ± 2.0	125 ± 2.0

LETTER	N	P	R	T	U Δ	V	W	Z
MM	24	28	24	45	47 ± 1.0	3.8	13	6.5

Δ ESSENTIAL DIMENSIONS



CAM ANGLE DEGREES	CAM RADIUS
0	0.742 R
30	0.753 R
60	0.764 R
90	0.773 R
120	0.784 R
150	0.796 R
180	0.818 R
210	0.854 R
240	0.901 R
270	0.945R
300	0.974R
330	0.995R
360	1.000R

FIG. 1 Hand-Operated Liquid Limit Device

the cam. (The preferred cam motion is a uniformly accelerlift curve.)

NOTE 1—The cam and follower design in Fig. 1 is for uniformly accelerated (parabolic) motion after contact and assures that the cup has no velocity at drop off. Other cam designs also provide this feature and may be used. However, if the cam-follower lift pattern is not known, zero velocity at drop off can be assured by carefully filing or machining the cam and follower so that the cup height remains constant over the last 20 to 45° of cam rotation.

6.1.5 *Carriage*, constructed in a way that allows convenient but secure adjustment of the height of drop of the cup to 10 mm (0.394 in.), and designed such that the cup and cup hanger assembly is only attached to the carriage by means of a removable pin.

6.1.6 *Motor Drive (Optional)*—As an alternative to the hand crank shown in Fig. 1, the device may be equipped with a motor to turn the cam. Such a motor must turn the cam at 2 ± 0.1 revolutions per second and must be isolated from the rest of the device by rubber mounts or in some other way that prevents vibration from the motor being transmitted to the rest of the apparatus. It must be equipped with an ON-OFF switch and a means of conveniently positioning the cam for height of drop adjustments. The results obtained using a motor-driven device must not differ from those obtained using a manually operated device.

6.2 *Flat Grooving Tool*—A tool made of plastic or noncorroding-metal having the dimensions shown in Fig. 2. The design of the tool may vary as long as the essential dimensions are maintained. The tool may, but need not, incorporate the gage for adjusting the height of drop of the liquid limit device.

NOTE 2—Prior to the adoption of this test method, a curved grooving tool was specified as part of the apparatus for performing the liquid limit test. The curved tool is not considered to be as accurate as the flat tool described in 6.2 since it does not control the depth of the soil in the liquid limit cup. However, there are some data which indicate that typically the liquid limit is slightly increased when the flat tool is used instead of the curved tool.

6.3 *Gage*—A metal gage block for adjusting the height of drop of the cup, having the dimensions shown in Fig. 3. The design of the tool may vary provided the gage will rest securely on the base without being susceptible to rocking, and the edge which contacts the cup during adjustment is straight, at least 10 mm (3/8 in.) wide, and without bevel or radius.

6.4 *Containers*—Small corrosion-resistant containers with snug-fitting lids for water content specimens. Aluminum or stainless steel cans 2.5 cm (1 in.) high by 5 cm (2 in.) in diameter are appropriate.

6.5 *Balance*, conforming to Specification D 4753, Class GP1.

6.6 *Storage Container*—A container in which to store the prepared soil specimen that will not contaminate the specimen in any way, and will prevent moisture loss. A porcelain, glass, or plastic dish about 11.4 cm (4½ in.) in diameter and a plastic bag large enough to enclose the dish and be folded over is adequate.

6.7 *Ground Glass Plate*—A ground glass plate at least 30

DIMENSIONS

LETTER	A[A]	B[A]	C[A]	D[A]	E[A]	F[A]
MM	2 ± 0.1	11 ± 0.2	40 ± 0.5	8 ± 0.1	50 ± 0.5	2 ± 0.1
LETTER	G	H	J	K[A]	L[A]	N
MM	10 MINIMUM	13	60	10 ±0.05	60 DEG ± 1 DEG	20

[A] ESSENTIAL DIMENSIONS

[B] BACK AT LEAST 15 MM FROM TIP

NOTE: DIMENSION A SHOULD BE 1.9–2.0 AND DIMENSION D SHOULD BE 8.0–8.1 WHEN NEW TO ALLOW FOR ADEQUATE SERVICE LIFE

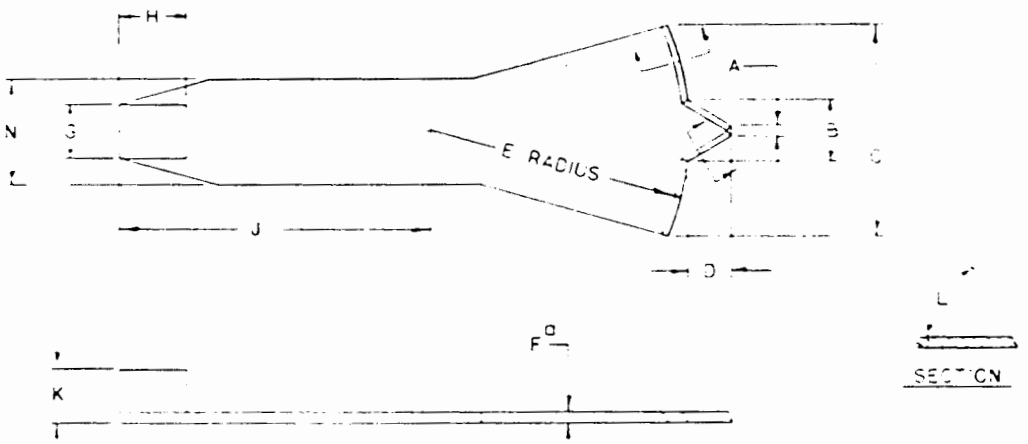
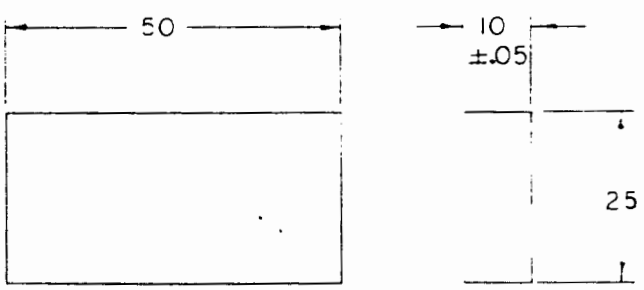


FIG. 2 Grooving Tool (Optional Height-of-Drop Gage Attached)



DIMENSIONS IN MILLIMETRES

FIG. 3 Height of Drop Gage

cm (12 in.) square by 1 cm (3/8 in.) thick for rolling plastic limit threads.

6.8 *Spatula*—A spatula or pill knife having a blade about 2 cm (3/4 in.) wide, and about 10 to 13 cm (3 to 4 in.) long.

6.9 *Sieve*—A 20.3-cm (8-in.) diameter, 425-µm (No. 40) sieve conforming to the requirements of Specification E 11 and having a rim at least 5 cm (2 in.) above the mesh. A 2-mm (No. 10) sieve meeting the same requirements may also be needed.

6.10 *Wash Bottle*, or similar container for adding controlled amounts of water to soil and washing fines from coarse particles.

6.11 *Drying Oven*, thermostatically controlled, preferably of the forced-draft type, capable of continuously maintaining a temperature of 110 ± 5°C (230 ± 9°F) throughout the drying chamber.

6.12 *Washing Pan*, round, flat-bottomed, at least 7.6 cm (3 in.) deep, and slightly larger at the bottom than a 20.3-cm (8-in.) diameter sieve.

7. Reagents and Materials

7.1 *Purity of Water*—Where distilled water is referred to in this test method, either distilled or demineralized water may be used.

8. Sampling

8.1 Samples may be taken from any location that satisfies testing needs. However, Methods C 702, Practice D 75, and Practice D 420 should be used as guides for selecting and preserving samples from various types of sampling operations. Samples which will be prepared using the wet preparation procedure (10.1) must be kept at their natural water content prior to preparation.

8.2 Where sampling operations have preserved the natural stratification of a sample, the various strata must be kept separated and tests performed on the particular stratum of interest with as little contamination as possible from other strata. Where a mixture of materials will be used in construc-

sieve, remove these particles by hand (if possible). If it is impractical to remove the coarser material by hand, remove small percentages (less than about 15 %) of coarser material by working the specimen through a 425-µm sieve using a piece of rubber sheeting, rubber stopper, or other convenient device provided the operation does not distort the sieve or degrade material that would be retained if the washing method described in 10.1.2 were used. If larger percentages of coarse material are encountered during mixing, or it is considered impractical to remove the coarser material by the methods just described, wash the sample as described in 10.1.2. When the coarse particles found during mixing are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425-µm sieve, but remove by hand or by washing.

10.1.1.3 Place the mixed soil in the storage dish, cover to prevent loss of moisture, and allow to stand for at least 16 h (overnight). After the standing period and immediately before starting the test, thoroughly remix the soil.

NOTE 5—The time taken to adequately mix a soil will vary greatly, depending on the plasticity and initial water content. Initial mixing times of more than 30 min may be needed for stiff, fat clays.

10.1.2 *Samples Containing Material Retained on a 425-µm (No. 40) Sieve:*

10.1.2.1 Select a sufficient quantity of soil at natural water content to provide 150 to 200 g of material passing the 425-µm (No. 40) sieve. Place in a pan or dish and add sufficient water to cover the soil. Allow to soak until all lumps have softened and the fines no longer adhere to the surfaces of the coarse particles (Note 6).

NOTE 6—In some cases, the cations of salts present in tap water will exchange with the natural cations in the soil and significantly alter the test results if tap water is used in the soaking and washing operations. Unless it is known that such cations are not present in the tap water, distilled or demineralized water should be used. As a general rule, water containing more than 100 mg/L of dissolved solids should not be used for washing operations.

10.1.2.2 When the sample contains a large percentage of material retained on the 425-µm (No. 40) sieve, perform the following washing operation in increments, washing no more than 0.5 kg (1 lb) of material at one time. Place the 425-µm sieve in the bottom of the clean pan. Pour the soil-water mixture onto the sieve. If gravel or coarse sand particles are present, rinse as many of these as possible with small quantities of water from a wash bottle, and discard. Alternatively, pour the soil water mixture over a 2.00-mm (No. 10) sieve nested atop the 425-µm sieve, rinse the fine material through and remove the 2.00-mm sieve. After washing and removing as much of the coarser material as possible, add sufficient water to the pan to bring the level to about 13 mm (½ in.) above the surface of the 425- µm sieve. Agitate the slurry by stirring with the fingers while raising and lowering the sieve in the pan and swirling the suspension so that fine material is washed from the coarser particles. Disaggregate fine soil lumps that have not slaked by gently rubbing them over the sieve with the fingertips. Complete the washing operation by raising the sieve above the water surface and rinsing the material retained with a small amount of clean water. Discard material retained on the 425-µm sieve.

10.1.2.3 Reduce the water content of the material passing limit. Reduction of water content may be accomplished by one or a combination of the following methods: (*a*) exposing to air currents at room temperature, (*b*) exposing to warm air currents from a source such as an electric hair dryer, or (*c*) decanting clear water from surface of the suspension. During evaporation and cooling, stir the sample often enough to prevent overdrying of the fringes and soil pinnacles on the surface of the mixture. For soil samples containing soluble salts, use a method of water reduction (*a* or *b*) that will not eliminate the soluble salts from the test specimen.

10.1.2.4 Thoroughly mix the material passing the 425-µm sieve on the glass plate using the spatula. Adjust the water content of the mixture, if necessary, by adding small increments of distilled or demineralized water or by allowing the mixture to dry at room temperature while mixing on the glass plate. The soil should be at a water content that will result in closure of the groove in 25 to 35 blows. Put the mixed soil in the storage dish, cover to prevent loss of moisture, and allow to stand for at least 16 h. After the standing period and immediately before starting the test, thoroughly remix the soil.

10.2 *Dry Preparation:*

10.2.1 Select sufficient soil to provide 150 to 200 g of material passing the 425-µm (No. 40) sieve after processing. Dry the sample at room temperature or in an oven at a temperature not exceeding 60°C until the soil clods will pulverize readily. Disaggregation is expedited if the sample is not allowed to completely dry. However, the soil should have a dry appearance when pulverized.

10.2.2 Pulverize the sample in a mortar with a rubber-tipped pestle or in some other way that does not cause breakdown of individual grains. When the coarse particles found during pulverization are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425-µm (No. 40) sieve, but remove by hand or other suitable means, such as washing.

10.2.3 Separate the sample on a 425-µm (No. 40) sieve, shaking the sieve by hand to assure thorough separation of the finer fraction. Return the material retained on the 425-µm sieve to the pulverizing apparatus and repeat the pulverizing and sieving operations as many times as necessary to assure that all fine material has been disaggregated and material retained on the 425-µm sieve consists only of individual sand or gravel grains.

10.2.4 Place material remaining on the 425-µm (No. 40) sieve after the final pulverizing operations in a dish and soak in a small amount of water. Stir the soil water mixture and pour over a 425-µm sieve, catching the water and any suspended fines in the washing pan. Pour this suspension into a dish containing the dry soil previously sieved through the 425-µm sieve. Discard material retained on the 425-µm sieve.

10.2.5 Proceed as described in 10.1.2.3 and 10.1.2.4.

MULTIPOINT LIQUID LIMIT—METHOD A

11. Procedure

ion, combine the various components in such proportions hat the resultant sample represents the actual construction ase.

8.3 Where data from this test method are to be used for orrelation with other laboratory or field test data, use the ame material as used for these tests where possible.

8.4 Obtain a representative portion from the total sample ufficient to provide 150 to 200 g of material passing the 425-m (No. 40) sieve. Free flowing samples may be reduced by he methods of quartering or splitting. Cohesive samples hall be mixed thoroughly in a pan with a spatula, or scoop nd a representative portion scooped from the total mass by naking one or more sweeps with a scoop through the mixed nass.

. Calibration of Apparatus

9.1 *Inspection of Wear:*

9.1.1 *Liquid Limit Device*—Determine that the liquid mit device is clean and in good working order. Check the llowing specific points.

9.1.1.1 *Wear of Base*—The spot on the base where the ip makes contact should be worn no greater than 10 mm ⅜ in.) in diameter. If the wear spot is greater than this, the ase can be machined to remove the worn spot provided the surfacing does not make the base thinner than specified in 1 ' the other dimensional relationships are maintained.

9 . *Wear of Cup*—Replace the cup when the grooving ol has worn a depression in the cup 0.1 mm (0.004 in.) ep or when the rim of the cup has been reduced to half its iginal thickness. Verify that the cup is firmly attached to cup hanger.

9.1.1.3 *Wear of Cup Hanger*—Verify that the cup hanger ot does not bind and is not worn to an extent that allows re than 3 mm (⅛ in.) side-to-side movement of the lowest nt on the rim.

.1.1.4 *Wear of Cam*—The cam shall not be worn to an ent that the cup drops before the cup hanger (cam ower) loses contact with the cam.

.1.2 *Grooving Tools*—Inspect grooving tools for wear on equent and regular basis. The rapidity of wear depends on material from which the tool is made and the types of s being tested. Soils containing a large proportion of sand icles may cause rapid wear of grooving tools; therefore, n testing these materials, tools should be inspected more uently than for other soils.

NOTE 3—The width of the tip of grooving tools is conveniently checked using a pocket-sized measuring magnifier equipped with a millimetre scale. Magnifiers of this type are available from most laboratory supply companies. The depth of the tip of grooving tools can be checked using the depth measuring feature of vernier calipers.

9.2 *Adjustment of Height of Drop*—Adjust the height of drop of the cup so that the point on the cup that comes in contact with the base rises to a height of 10 ± 0.2 mm. See Fig. 4 for proper location of the gage relative to the cup during adjustment.

NOTE 4—A convenient procedure for adjusting the height of drop is as follows: place a piece of masking tape across the outside bottom of the cup parallel with the axis of the cup hanger pivot. The edge of the tape away from the cup hanger should bisect the spot on the cup that contacts the base. For new cups, placing a piece of carbon paper on the base and allowing the cup to drop several times will mark the contact spot. Attach the cup to the device and turn the crank until the cup is raised to its maximum height. Slide the height gage under the cup from the front, and observe whether the gage contacts the cup or the tape. (See Fig. 4.) If the tape and cup are both contacted, the height of drop is approximately correct. If not, adjust the cup until simultaneous contact is made. Check adjustment by turning the crank at 2 revolutions per second while holding the gage in position against the tape and cup. If a faint ringing or clicking sound is heard without the cup rising from the gage, the adjustment is correct. If no ringing is heard or if the cup rises from the gage, readjust the height of drop. If the cup rocks on the gage during this checking operation, the cam follower pivot is excessively worn and the worn parts should be replaced. Always remove tape after completion of adjustment operation.

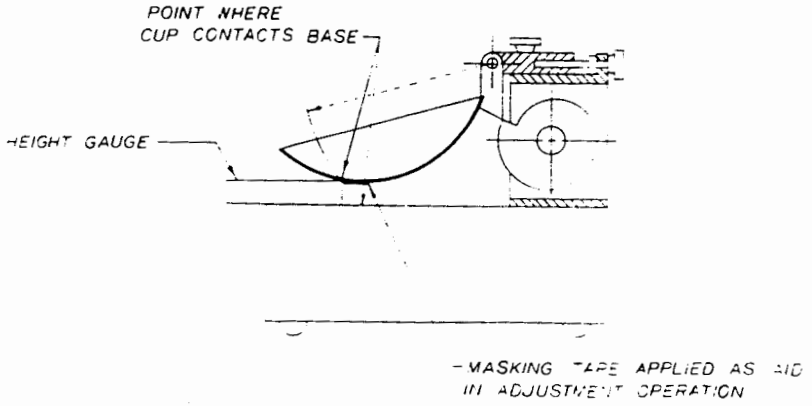
10. Preparation of Test Specimens

10.1 *Wet Preparation*—Except where the dry method of specimen preparation is specified (10.2), prepare specimens for test as described in the following sections.

10.1.1 *Samples Passing the 425-µm (No. 40) Sieve:*

10.1.1.1 When by visual and manual procedures it is determined that the sample has little or no material retained on a 425-µm (No. 40) sieve, prepare a specimen of 150 to 200 g by mixing thoroughly with distilled or demineralized water on the glass plate using the spatula. If desired, soak the soil in a storage dish with a small amount of water to soften the soil before the start of mixing. Adjust the water content of the soil to bring it to a consistency that would require 25 to 35 blows of the liquid limit device to close the groove (Note 5).

10.1.1.2 If, during mixing, a small percentage of material is encountered that would be retained on a 425-µm (No. 40)



liquid limit device at the point where the cup rests on the base, squeeze it down, and spread it into the cup to a depth of about 10 mm at its deepest point, tapering to form an approximately horizontal surface. Take care to eliminate air bubbles from the soil pat, but form the pat with as few strokes as possible. Keep the unused soil in the storage dish. Cover the storage dish with a wet towel (or use other means) to retain the moisture in the sample.

11.2 Form a groove in the soil pat by drawing the tool, beveled edge forward, through the soil on a line joining the highest point to the lowest point on the rim of the cup. When cutting the groove, hold the grooving tool against the surface of the cup and draw in an arc, maintaining the tool perpendicular to the surface of the cup throughout its movement. See Fig. 5. In soils where a groove cannot be made in one stroke without tearing the soil, cut the groove with several strokes of the grooving tool. Alternatively, cut the groove to slightly less than required dimensions with a spatula and use the grooving tool to bring the groove to final dimensions. Exercise extreme care to prevent sliding the soil pat relative to the surface of the cup.

11.3 Verify that no crumbs of soil are present on the base or the underside of the cup. Lift and drop the cup by turning the crank at a rate of 1.9 to 2.1 drops per second until the two halves of the soil pat come in contact at the bottom of groove along a distance of 13 mm (½ in.). See Fig. 6.

NOTE 7—Use of a scale is recommended to verify that the groove has closed 13 mm (½ in.)

11.4 Verify that an air bubble has not caused premature closing of the groove by observing that both sides of the groove have flowed together with approximately the same shape. If a bubble has caused premature closing of the groove, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving operation and repeat 11.1 to 11.3. If the soil slides on the surface of the cup, repeat 11.1 through 11.3 at a higher water content. If, after several trials at successively higher water contents, the soil pat continues to slide in the cup or if the number of blows required to close the groove is always less than 25, record that the liquid limit could not be determined, and report the soil as nonplastic without performing the plastic limit test.

11.5 Record the number of drops, N, required to close the groove. Remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove and including that portion of the groove in which the soil flowed together, place in a weighed container, and cover.

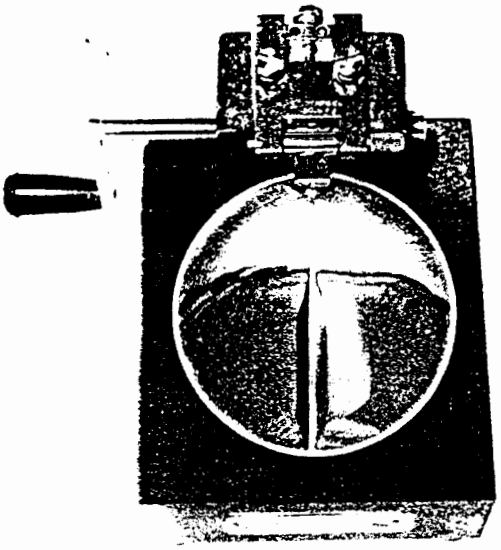
11.6 Return the soil remaining in the cup to the storage dish. Wash and dry the cup and grooving tool and reattach the cup to the carriage in preparation for the next trial.

11.7 Remix the entire soil specimen in the storage dish adding distilled water to increase the water content of the soil and decrease the number of blows required to close the groove. Repeat 11.1 through 11.6 for at least two additional trials producing successively lower numbers of blows to close the groove. One of the trials shall be for a closure requiring 25 to 35 blows, one for closure between 20 and 30 blows, and one trial for a closure requiring 15 to 25 blows.

11.8 Determine the water content, W^n, of the soil specimen from each trial in accordance with Test Method D 2216. Initial weighings should be performed immediately after completion of the test. If the test is to be interrupted for more than about 15 minutes, the specimens already obtained should be weighed at the time of the interruption.

12. Calculation

12.1 Plot the relationship between the water content, W^n, and the corresponding number of drops, N, of the cup on a semilogarithmic graph with the water content as ordinates on the arithmetical scale, and the number of drops as abscissas



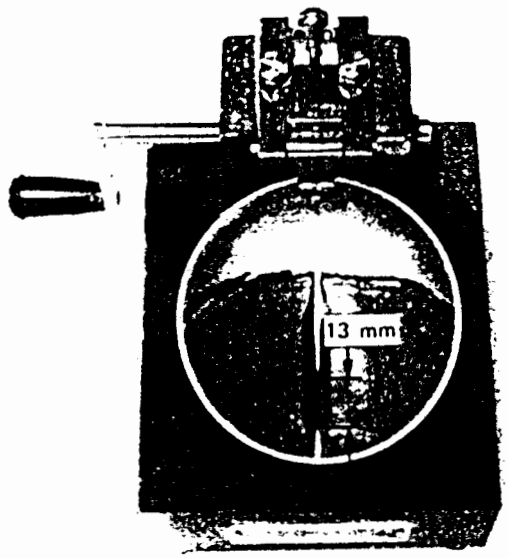


FIG. 6 Soil Pat After Groove Has Closed

on a logarithmic scale. Draw the best straight line through the three or more plotted points.

12.2 Take the water content corresponding to the intersection of the line with the 25-drop abscissa as the liquid limit of the soil. Computational methods may be substituted for the graphical method for fitting a straight line to the data and determining the liquid limit.

ONE-POINT LIQUID LIMIT—METHOD B

13. Preparation of Test Specimens

13.1 Prepare the specimen in the same manner in accordance with Section 10, except that at mixing, adjust the water content to a consistency requiring 20 to 30 drops of the liquid limit cup to close the groove.

14. Procedure

14.1 Proceed as described in 11.1 through 11.5 except that the number of blows required to close the groove shall be 20 to 30. If less than 20 or more than 30 blows are required, adjust the water content of the soil and repeat the procedure.

14.2 Immediately after removing a water content specimen as described in 11.5, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving and water content sampling orientations. Repeat 11.2 through 11.5, and, if the second closing of the groove requires the same number of drops or no more than two drops difference, secure another water content specimen. Otherwise, remix the entire specimen and repeat.

NOTE 8—Excessive drying or inadequate mixing will cause the number of blows to vary.

14.3 Determine water contents of specimens in accordance with 11.8.

15. Calculation

15.1 Determine the liquid limit for each water content specimen using one of the following equations:

$$LL = W^n \left(\frac{N}{25}\right)^{0.121}$$

or

$$LL = kW^n$$

where:

N = number of blows causing closure of the groove at water content,

W^n = water content, and

k = factor given in Table 1.

The liquid limit is the average of the two trial liquid limit values.

15.2 If the difference between the two trial liquid limit values is greater than one percentage point, repeat the test.

TABLE 1 Factors for Obtaining Liquid Limit from Water Content and Number of Drops Causing Closure of Groove

N (Number of Drops)	k (Factor for Liquid Limit)
20	0.974
21	0.979
22	0.985
23	0.990
24	0.995
25	1.000
26	1.005
27	1.009
28	1.014
29	1.018
30	1.022

PLASTIC LIMIT

16. Preparation of Test Specimen

16.1 Select a 20-g portion of soil from the material prepared for the liquid limit test, either after the second mixing before the test, or from the soil remaining after completion of the test. Reduce the water content of the soil to a consistency at which it can be rolled without sticking to the hands by spreading or mixing continuously on the glass plate or in the storage dish. The drying process may be accelerated by exposing the soil to the air current from an electric fan, or by blotting with paper that does not add any fiber to the soil, such as hard surface paper toweling or high wet-strength filter paper.

17. Procedure

17.1 From the 20-g mass, select a portion of 1.5 to 2.0 g. Form the test specimen into an ellipsoidal mass. Roll this mass between the palm or fingers and the ground-glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length (Note 9). The thread shall be further deformed on each stroke so that its diameter reaches 3.2 mm (1/8 in.), taking no more than 2 min (Note 10). The amount of hand or finger pressure required will v[illegible]reatly, according to the soil. Fragile soils of low pl[illegible]ity are best rolled under the outer edge of the palm or at the base of the thumb.

NOTE 9—A normal rate of rolling for most soils should be 80 to 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position. This rate of rolling may have to be decreased for very fragile soils.

NOTE 10—A 3.2-mm (1/8-in.) diameter rod or tube is useful for frequent comparison with the soil thread to ascertain when the thread has reached the proper diameter.

17.1.1 When the diameter of the thread becomes 3.2 mm, break the thread into several pieces. Squeeze the pieces together, knead between the thumb and first finger of each hand, reform into an ellipsoidal mass, and reroll. Continue this alternate rolling to a thread 3.2 mm in diameter, gathering together, kneading and rerolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a 3.2-mm diameter thread (see Fig. 7). It has no significance if the thread breaks into threads of shorter length. Roll each of these shorter threads to 3.2 mm in diameter. The only requirement for continuing the test is that they are able to be reformed into an ellipsoidal mass and rolled out again. The operator shall at no time attempt to produce failure at exactly 3.2 mm diameter by allowing the thread to reach 3.2 mm, then reducing the rate of rolling or the hand pressure, or both, while continuing the rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal mass nearer to the required 3.2-mm final diameter. If crumbling occurs when the thread has a diameter greater than 3.2 mm, this shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread 3.2 mm in diameter. Crumbling of the thread will manifest itself differently with the various types of soil. Some soils fall apart in numerous small aggregations of particles, others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally, the thread falls apart in many small platy particles. Fat clay soils require much pressure to deform the thread, particularly as they approach the plastic limit. With these soils, the thread breaks into a series of barrel-shaped segments about 3.2 to 9.5 mm (1/8 to 3/8 in.) in length.

17.2 Gather the portions of the crumbled thread together and place in a weighed container. Immediately cover the container.

17.3 Select another 1.5 to 2.0-g portion of soil from the

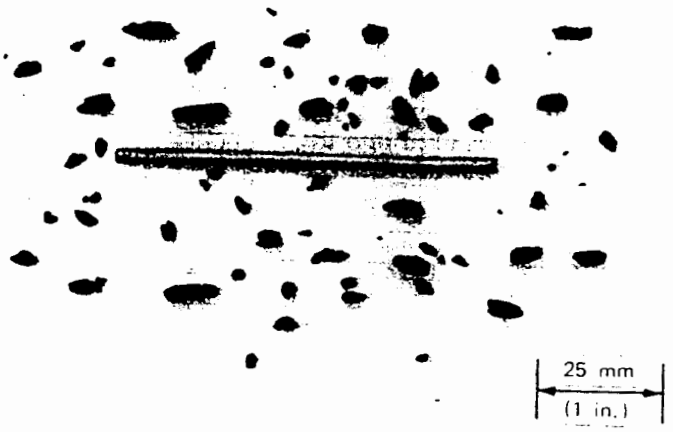


TABLE 2 Table of Precision Estimates[A]

Material and Type Index	Standard Deviation[B]	Acceptable Range of Two Results[B]
Single-operator precision:		
Liquid Limit	0.8	2.4
Plastic Limit	0.9	2.6
Multilaboratory precision:		
Liquid Limit	3.5	9.9
Plastic Limit	3.7	10.6

[A] The figures given in Column 2 are the standard deviations that have been found to be appropriate for the test results described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between the two properly conducted tests.

[B] These numbers represent, respectively, the (1S) and (D2S) limits as described in Practice C 670.

original 20-g specimen and repeat the operations described in 17.1 and 17.2 until the container has at least 6 g of soil.

17.4 Repeat 17.1 through 17.3 to make another container holding at least 6 g of soil. Determine the water content of the soil contained in the containers in accordance with Test Method D 2216.

18. Calculation

18.1 Compute the average of the two water contents. Repeat the test if the difference between the two water contents is greater than the acceptable range for two results listed in Table 2 for single-operator precision. The plastic limit is the average of the two water contents.

PLASTICITY INDEX

19. Calculation

19.1 Calculate the plasticity index as follows:

$$PI = LL - PL$$

where:
LL = liquid limit,
PL = plastic limit.

19.1.1 Both LL and PL are whole numbers. If either t liquid limit or plastic limit could not be determined, or if t plastic limit is equal to or greater than the liquid limit, rep the soil as nonplastic, NP.

20. Report

20.1 Report the following information:

20.1.1 Sample identifying information,

20.1.2 Any special specimen selection process used, su as removal of sand lenses from undisturbed sample,

20.1.3 Report sample as air-dried if the sample w air-dried before or during preparation,

20.1.4 Liquid limit, plastic limit, and plasticity index the nearest whole number, omitting the percent designatic If the liquid limit or plastic limit tests could not performed, or if the plastic limit is equal to or greater th the liquid limit, report the soil as nonplastic, NP,

20.1.5 Estimate of the percentage of sample retained the 425-µm (No. 40) sieve, and

20.1.6 Procedure by which liquid limit was performed it differs from the multipoint method.

21. Precision and Bias

21.1 *Precision*—Criteria for judging the acceptability liquid limit and plastic limit test results obtained by this t method on material are given in Table 2. The estimates precision are based on the results of an interlaboratory stu that included eleven laboratories performing the multipo test (Method A) on three replicate samples of soil havin liquid limit of 64 and a plastic limit of 22.

21.2 *Bias*—There is no acceptable reference value for t test method; therefore, bias cannot be determined.

22. Keywords

22.1 activity; Atterberg limits; liquid limit; plastic index; plastic limit

APPENDIX

(Nonmandatory Information)

X1.1 A device for measuring the resilience of liquid limit device bases is shown in Fig. X1.1. The device consists of a clear acrylic plastic tube and cap, a 5/16-in. diameter steel ball, and a small bar magnet. The cylinder may be cemented to the cap or threaded as shown. The small bar magnet is held in the recess of the cap and the steel ball is fixed into the recess in the underside of the cap with the bar magnet. The cylinder is then turned upright and placed on the top surface of the base to be tested. Holding the tube lightly against liquid limit device base with one hand, release the ball pulling the magnet out of the cap. Use the scale markings the outside of the cylinder to determine the highest p reached by the bottom of the ball. Repeat the drop at l three times, placing the tester in a different location for e drop. Tests should be conducted at room temperature.

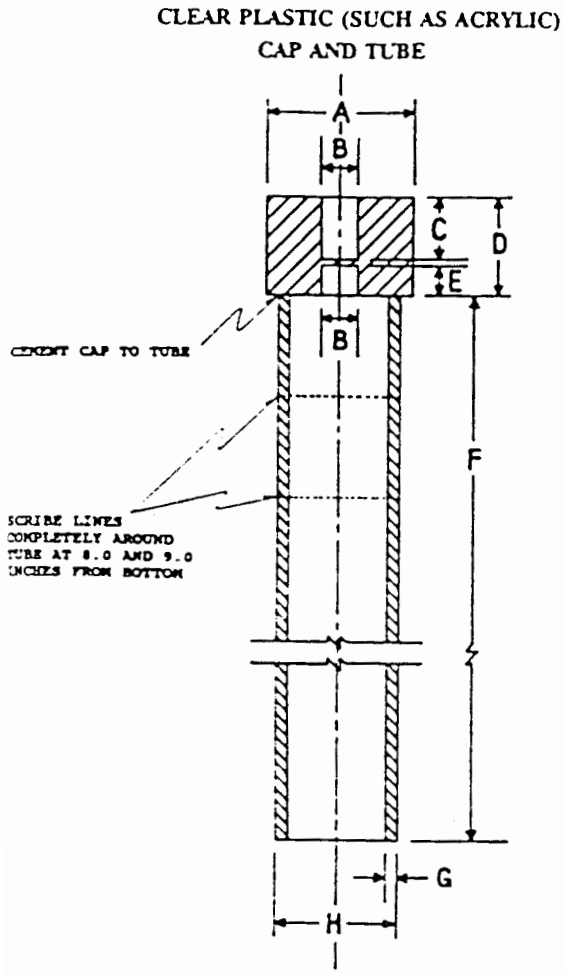


TABLE OF MEASUREMENTS

DIMENSION	DESCRIPTION	ENGLISH, in.	METRIC, mm
A	DIAM. OF CAP	1 1/2	38.10
B	DIAM. OF HOLE	3/8	9.52
C	DEPTH OF HOLE	10/16	15.88
D	HEIGHT OF CAP	1	25.40
E	DEPTH OF HOLE	5/16	7.94
F	LENGTH OF TUBE	10	254.00
G	WALL THICKNESS	1/8	3.18
H	O.D. OF TUBE	1 1/4	31.75

FIG. X1.1 Resilience Tester

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RECOMMENDED PRACTICE for CORE-ANALYSIS PROCEDURE

Foreword

a. This recommended practice was formulated by the Subcommittee on Core-analysis Procedure, the membership of which is listed below. It is published under the sponsorship of the Steering Committee on Production Practice and the Executive Committee on Drilling and Production Practice, of the Institute's Division of Production.

b. This recommended practice has been prepared with two uses in mind:

1. As an aid in selecting methods of core analysis applicable to a specific problem.
   A comparison of various reliable methods is made under each core-analysis practice, giving a brief statement of the principles, advantages, and limitations.
2. As a guide in testing.
   Representative procedures for the various core-analysis methods are described in some detail for those wishing to use the recommended practice for this purpose.

c. The content of this recommended practice was gathered by a representative of each API district from operators and service companies actively using core analysis in that district. These data were compared and screened to meet the needs of many types of samples. Only techniques which are known to give reproducible and accurate results on a routine basis have been included in the final composite. Acknowledgment is made to these companies for their contributions to this effort.

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1.0 GENERAL FOREWORD

The objective of this manual is to present recommended acceptable practices for routine core analysis. These selected methods are based on sound scientific principles and will yield data that are reproducible and significant to the resolution of the problems for which the data are intended. Routine core analyses, for purposes of this recommended practice, have been defined as determination of fluid saturations, porosity, and gas permeability. Core-water salinity and oil gravity have been added as supplementary tests.

Core analysis provides direct measurement of some of the basic rock properties which are needed to determine the total fluid content, the distribution, and the flow behavior of the reservoir fluids or injected fluids. The importance of reliable and representative core data cannot be over-emphasized. These data are basic in evaluating oil reservoirs. The interpretation of other logging methods is established by correlation with core-analysis data.

Core-analysis problems fall into two general categories, viz., the determination of basic data and the interpretation of the analytical results. The determination of reliable basic data depends upon the intelligent selection of test samples, the careful preparation of these samples for testing, and the use of test methods and equipment based on proved scientific principles. The proper interpretation of the analytical results must be based on understanding of the changes which occur during coring and lifting the core to the surface.

All currently used coring procedures alter in some degree the fluid content of the reservoir rock during the coring process. The drilling fluid is jetted against the formation ahead of the coring bit and against the peripheral surface of the core as it passes into the core barrel. The core is thus subjected to the flushing action of the drilling-fluid filtrate. Some of the factors which contribute to the degree of flushing are: *1*, rate of bit penetration; *2*, vertical and horizontal permeability of the formation; *3*, filtrate-loss properties of the drilling fluid; *4*, pressure difference between the drilling-fluid stream and formation; and *5*, core diameter. Since the bit and core barrel tend to remove filter cake from the surface of the core, the degree of flushing varies more with drilling-fluid pressure and rate of coring than with fluid-loss properties of the drilling fluid. Normally, most free gas and a portion of the liquid content are displaced from the core by drilling-fluid filtrate. In many cases, where water-base drilling fluid is used, the flushing action of the drilling-fluid filtrate may displace the oil until, at complete flushing, the oil saturation is decreased to what is considered the residual-oil saturation of the sample. The original water contained in the rock may also be displaced by the flushing action to such an extent that the fluid content of the recovered core may be predominantly from the drilling fluid.

As the partially or completely flushed core is brought to the surface, the pressure and temperature are reduced from reservoir to atmospheric conditions. The gas dissolved in the oil and water expands and subjects the core to a solution-gas drive and expulsion of liquids continues as the core nears the surface and the pressure declines. Thus, the core as recovered at the surface may have been subjected to the equivalent of a liquid displacement, followed by a solution-gas drive. Recognition that these conditions are imposed on the core is essential to proper interpretation of the data from core analysis.

Differences in rock characteristics, the type of core sample recovered, or additional tests to be made on the sample often require that a specific procedure be used for testing a given core. Thus, this recommended practice lists a number of different procedures for some of the various core-analysis measurements. The major principles involved, the types of data obtained, the procedures, and the advantages and the limitations of the various recommended core-analysis procedures are presented.

2.0 FIELD CORE SAMPLING AND PRESERVATION

Field sampling of cores should represent the best possible practices because the value of all core analysis is limited by this initial operation. The objective of a standard field core-sampling procedure is twofold:

a. To obtain samples which will give results representative of the formation.

b. To obtain samples under a uniform procedure so that the results will be independent of the sampler.

The two major problems confronting those sampling reservoir rocks for core analysis are:

a. The selection of representative samples from each core.

b. The wrapping and preserving of the core samples quickly enough to prevent loss of fluids from within the core or the absorption of foreign fluids by the core.

The selection of samples is fairly simple for relatively uniform formations. However, where a formation contains widely varying lithology and heterogeneous porosity types — such as conglomerates, weathered cherts, vugular or fractured carbonates, and inter-laminated shales and sands — the proper selection of representative samples requires greater care. A trained person — engineer, geologist, etc. — should follow a fixed sampling procedure at the well location. All or portions of the core should be preserved and sent to the laboratory according to kind of rock cored, amount of recovery, and purpose of laboratory analysis. The actual preservation of the core fluids and the distribution of the fluids in the core as sampled are the most important objectives of core preservation. In order to obtain these, a uniform procedure for sampling and preservation must be conducted. The following procedures have been selected as those which will yield samples that allow the most reliable and representative core analysis.

2.1 CORES FOR CONVENTIONAL CORE ANALYSIS

2.11 SAMPLING

2.111 Removal from the Core Barrel

Cores should not be allowed to remain in the core barrel after reaching the surface since fluids from the mud may be absorbed by capillarity. This will change the equilibrium conditions established by expanding gas as a sample comes to the surface. Any delay in removal of the core from the barrel should be noted and reported.

The core should be removed from the core barrel as gently as possible to cause a minimum alteration of the core and its fluid content. It is recommended that the core either be allowed to slide gradually from the barrel by gravity, by raising one end of the barrel, or by pushing it using a plunger or rod. Light hammering or jarring may be necessary to move the core, particularly hard cores. However, heavy hammering or pounding the core barrel on its end should be avoided. These rough practices may alter the core, especially if it is a soft sand. Even in a more consolidated core, jarring and hammering may cause part of the core to become crushed or fractured.

Only if the core cannot be removed by the foregoing methods should it be pumped out with a fluid. If this is necessary, a suitable piston arrangement should be used which will not allow fluids to contact and to contaminate the core. The drilling fluid should be used if pumping directly with fluids is necessary. The use of fresh water or other fluids foreign to the core should be avoided. If water is forced past the piston and forced into a core, high water-saturation values will be obtained by core analysis. Any excessive pressuring of the barrel may cause some fluid from mud and mud cake to penetrate the core. Any difficulty or irregularity in removing the core should be noted, e.g., pressure used if pumped out with mud, loss of consolidated material, etc.

2.112 Labeling and Logging of the Core

The cores as they are removed from the core barrel should be placed in appropriately marked trays or troughs taking care to keep the tray sequence and orientation in order. Protection from high temperatures, i.e., direct sunlight, hot engines, etc., or from rain, strong wind, etc. should be provided. Accurate measurements of recovery should be made and recorded. Any recovery in excess of the core cut should be reported, as well as any lost recovery. Log the lost recovery at the bottom of each core interval, unless some special observation indicates an exception should be made. Such exceptions should be noted. The engineer or person in charge should use the best information available when allocation of lost recovery is required. Data and observations such as the following are always helpful.

a. Drilling time per foot (may indicate formation breaks).
b. General conditions of the core (continuity, broken section, etc. should be noted).
c. Condition of the core catcher (if badly damaged, bottom of core may have dropped out and may be subsequently recovered).

In some cases, it may be possible to assign lost recovery to a more exact depth by using electrical or other types of surveys.

2.113 Cleaning the Core

It is recommended that the core be wiped to remove soft mud cake and excess mud as soon as possible following its removal from the core barrel. The excess mud should be wiped off with a damp—not wet nor dry—rag. Preferably, the rag should be dampened in drilling fluid and wrung out as often as necessary to prevent its becoming too wet. Core samples to be sent to the laboratory should never be washed with water or any other liquid after removal from the barrel. Depending upon the firmness of the core, there may be a question whether the mud cake should be removed either by wiping with a rag or scraping with a knife. If field examination is required, it may be necessary to scrape part of the core in order to make the examination. Emphasis must be placed on never washing the mud from the core. In any event, the wiping, examination, and sampling procedure following removal from the core barrel should take a minimum of time. The time a core is exposed to the drilling fluid and the atmosphere will affect the subsequent core analysis.

Even a few minutes exposure of cores, depending upon atmospheric conditions, can cause the loss of both water and light hydrocarbon fractions. Tests have shown that as little as ½-hour exposure to the atmosphere can result in 10- to 25-percent loss in water content. If the core is accidentally washed with water, allowed to remain in the core barrel, or let stand before sealing in a container, then a notation of the washing, the number of hours in the core barrel, or the length of exposure time before sealing in the container should be made.

2.114 Frequency and Size of Sample

Retaining the entire core is the preferred practice. Where the entire core is not retained, it is recommended that at least every foot normally be sampled. Some consideration should be given to the proper statistics of sampling for various types of rocks.[1, 2, 3]

Where cores are not entirely saved, it is desirable that those samples selected should be a minimum of 4 in. to 6 in. in length. *All cores taken by wire line should be saved.*

2.115 Sampling Procedure Where the Entire Core Is Not Saved

The following sampling procedure is recommended to minimize the time a core is exposed to both drilling fluid and the atmosphere.

a. As soon at the recovery has been accurately measured, sufficient mud cake is removed to allow inspection and a proper selection of samples. The core should be cleaned of excessive mud by wiping, wrapped with foil or plastic to minimize changes in the core, and replaced in the proper position in the tray.
b. The lithology and the depth of the samples should be accurately determined and recorded.
c. The samples should then be packaged in a manner consistent with the test desired and the expected time lapse before testing.
d. Both the samples and the container should be labeled with the well name and depth. Any additional pertinent data should accompany the cores to the testing laboratory.
e. If exposure is longer than 30 min., conditions of weather, temperature, etc. should be noted. Any large time lapse between sampling the first section of a given core and the last section should be noted.

[1]References are given in Section 8.0.

2.116 Data Sheet

A suitable data sheet should be provided for and completed by the sampler to supply as complete a record as possible of the conditions of sampling. This record will be valuable in qualifying interpretation of the subsequent core-analysis data. Further, this record may suggest either that certain additional tests be run to supplement routine tests, or that certain tests would not yield significant data. This will result in the most useful data for the least time and money. Fig. 2.116F1 is an example form, and the use of this or a similar form is recommended.

It is important to have as much pertinent data as possible accompany the sample. Following is listed the desirable information:

a. A description of the lithology.
b. A designation of the mud type, weight, filter loss, chlorides, and chemical treatments.
c. Gravity of the oil produced in that zone.
d. Designation of tests desired.
e. Person's name to whom data should be reported via telephone, air mail, or regular mail.
f. Company, field, well, and zone.
g. Any pertinent data not listed, e.g., time core exposed before sampling, weather, difficulty in removing from core barrel, time to pull core, etc.
h. Core record and drilling log.
i. Well logs (if available).
j. Well elevation, designated as kelly bushing (KB) or ground level (GL).

2.12 PRESERVATION OF CORES FOR ANALYSIS

The preservation of a core is an attempt to maintain it, prior to analysis, in the same condition as existed upon its removal from the core barrel. In the process of cutting a core, recovering it, and bringing it to the surface, the fluid content of the rock is altered by unavoidable processes. Careless or incorrect practices in sampling and packaging cause further alteration of the core and its fluids, thereby making the core even less representative of the formation conditions.

Preservation and packaging of cores may vary depending upon the test required and the length of time before testing. If the core samples selected for analysis are to be analyzed for fluid content, it is necessary that they be preserved for transportation to the laboratory in such a way as to prevent the evaporation of liquids and the migration of fluids within the sample itself.

An additional objective of the preservation is to prevent breakage of the cores during shipment and storage. Hard and consolidated cores may be durable enough not to require special precautions for support. However, special care should be taken to give adequate support to cores which are soft or poorly consolidated. The use of a container of approximately the same diameter as the core may prevent breaking of some loosely consolidated samples during shipment. Aluminum foil may be used to protect loosely consolidated sand from damage during shipment.

The use of glass jars, easily deformable plastics, paper cartons, and other non-rigid containers should be avoided if the core samples are to be shipped or will be subjected to other rough handling. Metal or rigid plastic containers are recommended.

2.13 METHODS OF PRESERVING CORES UNTIL TESTED

The best preservation method will be the one that experience indicates to be most satisfactory for the type of core in question. Frequently, the method will depend upon the nature of the rock. Therefore, general use of one specific method of preservation may not be proper. Further, the techniques required to preserve cores for testing may depend upon the length of time for storage and the nature of the test desired. Some variation in the technique of preserving the cores may depend upon whether the cores will be tested in local areas or whether they must be prepared for long-distance shipping. Preferred methods to preserve cores for laboratory analysis, without significance to the order of listing, are:

a. Sealing in air-tight metal cans.
b. Sealing in steel, aluminum, or plastic tubes, using suitable couplings, pipe caps, or O-ring seals.
c. Sealing in plastic bags.
d. Freezing with dry ice.
e. Wrapping in metal foil or plastic tape.
f. Coating with plastic.

2.131 Sealing in Air-tight Cans

Core samples selected for analysis, particularly when saturation determinations are critical, may be sealed in metal cans. This is an efficient, rapid method. Cores may be canned directly or sealed in cans after a preliminary wrapping using aluminum foil, or polyethylene or other suitable plastic. There should be a minimum of space between the core sample and the can, particularly if no preliminary wrap is used. If the core is friable, some provision to prevent its movement in the can during shipping should be made. The use of paper, wax paper, cardboard, or materials which may absorb moisture or oil from the core should be avoided. If the entire core is shipped to the laboratory following the selection and canning of samples for fluid-saturation tests, the canned samples — each properly labeled for depth — may be replaced in the position from which they were removed from the core. The core should be properly logged on its arrival at the laboratory. Normally, it is recommended that cores not be canned with any fluid surrounding the core. The sealed container should not be subjected to large temperature fluctuations, if possible, in order to minimize evaporation and condensation of core fluids in the container.

2.132 Sealing in Air-tight Steel, Aluminum, or Plastic Tubes

Using suitable couplings, caps, or O-ring seals, the entire core may be preserved for analysis by placing it in steel, aluminum, or plastic tubes. A close-fitting tube is desirable. Normally, no fluids should be used in packaging the cores although the cores may be pre-wrapped in plastic or metal foil. Large variations in temperature during storage and shipment should be avoided.

2.133 Sealing in Plastic Bags

Core samples which are sealed in plastic bags should have a minimum of air space between the core and the bag wall. Any excess bag can be folded against the core wall and taped in place to assure a tight fit. Excess air may be withdrawn by suction. Care must be taken in adjusting the bag so that sharp points on the core do not puncture the bag. In some cases, more than one layer of plastic bag or sheeting may be used for wrapping cores. Cores sealed in plastic bags may be packed in boxes with suitable packing to prevent their being broken in shipment, or they may be canned or placed in metal or plastic tubes. The same precautions must be observed for cores sealed in plastic bags as for those sealed in cans, so far as exposure to extremes of temperature is concerned.

DATA FOR CORE ANALYSIS

1. Operator_____
2. Well_____
3. Field_____
4. County_____
5. State_____
6. Location_____
7. Elevation_____ { GR / DF / RB
8. Formation_____
9. Core recorder? Yes_____ No_____
10. Crude-oil gravity_____° API Est._____ Meas._____
11. Formation-water chlorides_____ppm
12. Analysis requested:
    a. Routine core analysis
    - ☐ Fluid saturation
    - ☐ Porosity
    - ☐ Permeability
    - ☐ _____
    - ☐ _____

    b. Special tests
    - ☐ _____
    - ☐ _____
    - ☐ _____
    - ☐ _____

13. Core No._____
14. Date cored_____
15. Sampled by_____
16. Date shipped_____
17. Shipped by_____
18. Shipped via_____
19. Type of core:
    - ☐ Conventional
    - ☐ Diamond
    - ☐ Wire-line
    - ☐ Side wall
    - ☐ Cable-tool
    - ☐ _____
20. Drilling-fluid data:
    - Type_____
    - Weight_____
    - Viscosity_____Marsh sec.
    - Water loss_____cc/_____
    - Chlorides_____ppm
    - pH_____
21. Send preliminary results
    - To_____
    - At_____Results Desired
    - By_____(Hour—Day)
    - For_____(Operation)
22. Analysis requested by_____
23. Lithologic abbreviations:[4]

anhy—anhydrite	gyp—gypsum	sa—rock salt
cht—chert	ig—igneous	sd—sand
cly—clay	ls—limestone	sh—shale
cgl—conglomerate	meta—metamorphic	slt—silt
dol—dolomite	mrl—marl	ss—sandstone

24. Remarks_____

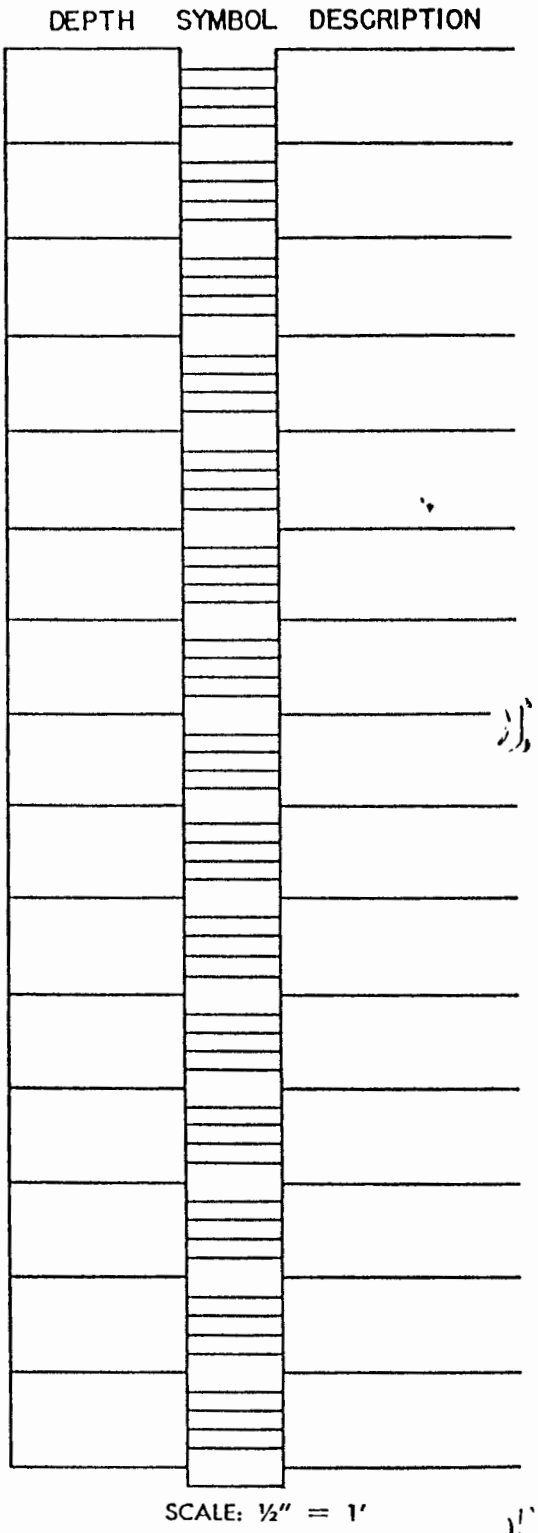


FIG. 2.116F1—EXAMPLE FORM FOR CORE-ANALYSIS DATA

2.134 Freezing with Dry Ice
(U. S. Patent No. 2,617,296)

Cores which are preserved by freezing should be frozen very rapidly by application of dry ice. Slow freezing may result in the migration of fluids within the core structure or breakage of the core. Cores are commonly frozen when the core-analysis laboratories are local. Preservation by freezing of cores for extended storage requires refrigeration or continuous repacking with dry ice. If it is necessary to allow the core to warm to room temperature before testing, the condensation of moisture from the atmosphere onto the core surface must be prevented. Slow thawing of the core will cause some redistribution of the fluids within the core matrix.

Freezing will affect properties of cores flushed with fresh water more than those flushed with saline mud filtrate. These effects will decrease with liquid saturation.

2.135 Wrapping in Metal Foil and Plastic Tape

Cores should be wrapped with metal foil and plastic tape only if they are consolidated enough to withstand shipment and will be analyzed in a few hours. Care must be taken that the foil is not punctured by sharp points of the core. To preclude this, cores are often double- or triple-wrapped. Effective wrapping with metal foil is best accomplished by lapping the edges along the length of the core as well as on the ends and folding once or twice, finally pressing the folded edges down against the core. The use of a self-sealing vinyl tape has been substituted for plastic, after foil wrapping. Foil wrapping prevents the adhesive on the tape from absorbing oil from the core.

2.136 Plastic Coatings

Plastic coatings have been used where cores are not to be tested within a few hours and need to be transported over distances which may involve rough handling. The cores should be scraped reasonably free of mud cake, dipped in the molten plastic, tagged, and shipped in this condition. One procedure used for dipping cores in molten plastic requires a thermostatically controlled melting pot to hold the plastic in a barely melted condition. The core to be coated is grasped by tongs or by the thumb and forefinger at one end, submerged about two-thirds of its length in the molten plastic, immediately removed, and allowed to cool and set for a few seconds. It is then grasped by the coated end and dipped, allowing the second plastic layer to overlap the initial one.

A dip such as that just described should leave a plastic layer about $\frac{1}{16}$-in. thick, completely surrounding and sealing the core with no air space between, yet not penetrating the core beyond one sand grain depth. If transportation over long distances is anticipated or if cementation of the core is not good, it may be advisable to repeat the dipping process, thereby building up the thickness of the coating. This can be continued to achieve any reasonable thickness desired. However, for normal physical protection, the initial dip coat is satisfactory. Very poorly consolidated cores may be wrapped in foil before dipping.

Plastic used for coating cores must have certain properties, as follows:

a. It must be dimensionally stable over long periods of time.
b. It must not react with oil or water.
c. It must not contain oleic acid, oil, solvent, or any other liquid which may be exuded when set.
d. It must be impermeable to gases, oils, and water when set.
e. It must have a low melting point, preferably below 200 F. maximum.
f. It must have a fairly low viscosity when melted. The viscosity should be similar to that of an average oil paint such that it will pour readily or drip slowly from a small opening, yet will not quickly penetrate capillary openings.
g. When removed from heat and exposed to normal air temperatures, it should dry and set tack-free within 5 to 15 sec.
h. When set, it should be tough but pliable, slightly elastic but with good tensile strength, and not melt at temperatures below 180 F.

2.14 PRECAUTIONS

Sampling and wrapping should be conducted in such a manner as to prevent both loss of the interstitial fluids and contamination with foreign fluids. Thus the core should never be washed with water or oils before packaging. For a reliable determination of fluid content of cores, a uniform procedure must be observed for core sampling and preservation. Some precautions for packaging samples are listed.

a. All samples should be sealed in containers as soon as possible after removal from the core barrel. Even after sealing, the samples should be kept at reasonably constant temperature to prevent evaporation and condensation in the packages.
b. Use a can or container with approximately the same diameter as the core to minimize the air space between the core and the sample which might lead to evaporation losses. This will also minimize condensation losses on the inside surface of the container and prevent breaking of the more loosely consolidated samples during shipment.
c. Do not put cloth, paper, cellophane, wax paper, or any material with fine capillaries in the container if a fluid-saturation test is required, unless the core is adequately protected by methods described.
d. Do not dip the core in wax.
e. Unconsolidated sand cores require very careful handling. Place in a container only material that is least contaminated with drilling mud. In such cases, it is more useful to have a small, clean sample than a large, badly contaminated one. When the sand and drilling mud are mixed together, there is little use in canning the sample. However, if a test is desired to determine the presence of oil, as clean a sample as possible should be canned and a notation made on the label that the sample is contaminated with drilling mud. Thus unnecessary laboratory testing and improper interpretation of the tests which are made can be avoided.
f. Do not can an unconsolidated sand sample in the same container with a consolidated or hard sample.
g. Should any core be accidentally washed with water or oil, a notation of the washing or exposure should be made.
h. Label each container properly, indicating well name and depths of interval represented.

i. If the engineer or person in charge is not able to be on location when the core is pulled, he should leave instructions for the core to be preserved in containers according to the foregoing rules. Inspection and description of the core could be made later at the well site or, preferably, at the laboratory when opening the container for analysis.

j. Cores which are canned should have the interior of the can inspected for free oil and water at the time of opening.

k. Upon arrival at the laboratory, cores should remain sealed in their original containers until time for analysis.

2.2 CORES FOR FULL-DIAMETER CORE ANALYSIS

In several principal producing formations, the major porosity and permeability are due to fractures and solution cavities. The samples used in conventional core analysis are too small to properly evaluate these non-homogeneous formations. Procedures have been developed to use full-diameter cores for analysis and thus obtain the maximum sample size.

2.21 SAMPLING

2.211 Sampling and Cleaning the Core

Identical sampling procedures and precautions used for conventional core analysis should be used in the sampling and well-site cleaning of cores on which full-diameter core analysis is to be obtained (see 2.11). Breaking the core into small sections for visual examination should be held to a minimum. Sample sections of 12 to 20 in. should be marked off along the entire core in order to take advantage of the long pieces recovered. Some samples may consist of a single 12- to 20-in. piece; whereas other samples may be composed of several pieces, 4 in. or longer.

2.212 Frequency of Sampling

Retaining the entire core is the preferred practice. If the entire core is not retained, it is recommended that at least every foot normally be sampled. Those samples selected should be a minimum of 4 in. to 6 in. in length. Some consideration should be given to proper statistics of sampling.[1,2,3]

When the core is received at the laboratory, it should be examined closely. Detailed information is frequently desired relating to the number, size, and major linear direction of fractures, size and distribution of vugs, and abrupt changes in lithology.*

2.213 Data Sheet

Refer to 2.116.

2.22 PRESERVATION OF CORES FOR ANALYSIS

The objectives and methods used for preservation of full-diameter cores are the same as for conventional core analysis. Refer to 2.13.

2.23 PRECAUTIONS

Refer to 2.14.

*Some laboratories are equipped to photograph a 50-ft section of core, and enlargements can be made of sections of particular interest for detailed study of the fracture or vug system. Other test equipment for use at this stage of analysis, now available in some laboratories, involves a gamma-ray unit for obtaining a log of the core on the layout table. A comparison of this detailed gamma-ray log and the corresponding analysis and visual examination of the core with a "down-hole" log permits precise and accurate selection of the completion depths in zones of alternating pay and non-pay intervals.

2.3 UNCONSOLIDATED AND SIDEWALL SAMPLING AND PRESERVATION

Unconsolidated samples, sidewall samples, and other small samples normally will not yield reliable quantitative data. If such samples can be tested by conventional analysis, then procedures in that section should be followed. However, in most cases, one can expect only qualitative results. They will be chiefly useful for lithology, tests for the presence of oil, and well-log correlation.

2.31 UNCONSOLIDATED SAMPLES

Unconsolidated samples should be sampled to give a small, clean sample, rather than a large, contaminated one. Because of the fragile condition of many unconsolidated samples, they should be handled with as much care as possible. Place in the container only material that is uncontaminated with drilling fluid. If the drilling fluid and sand are mixed together, there is little use in canning the sample. However, if it is desired to test for the presence and properties of oil, as clean a sample as possible should be preserved and a notation made on the label that the sample is contaminated with drilling fluid. Such a notation will prevent unnecessary laboratory testing and improper interpretation of the tests which are made.

Metal foil may be used to support and protect loosely consolidated samples. The metal foil may be folded carefully around the sample and shaped to conform to the sample.

2.32 SIDEWALL SAMPLES

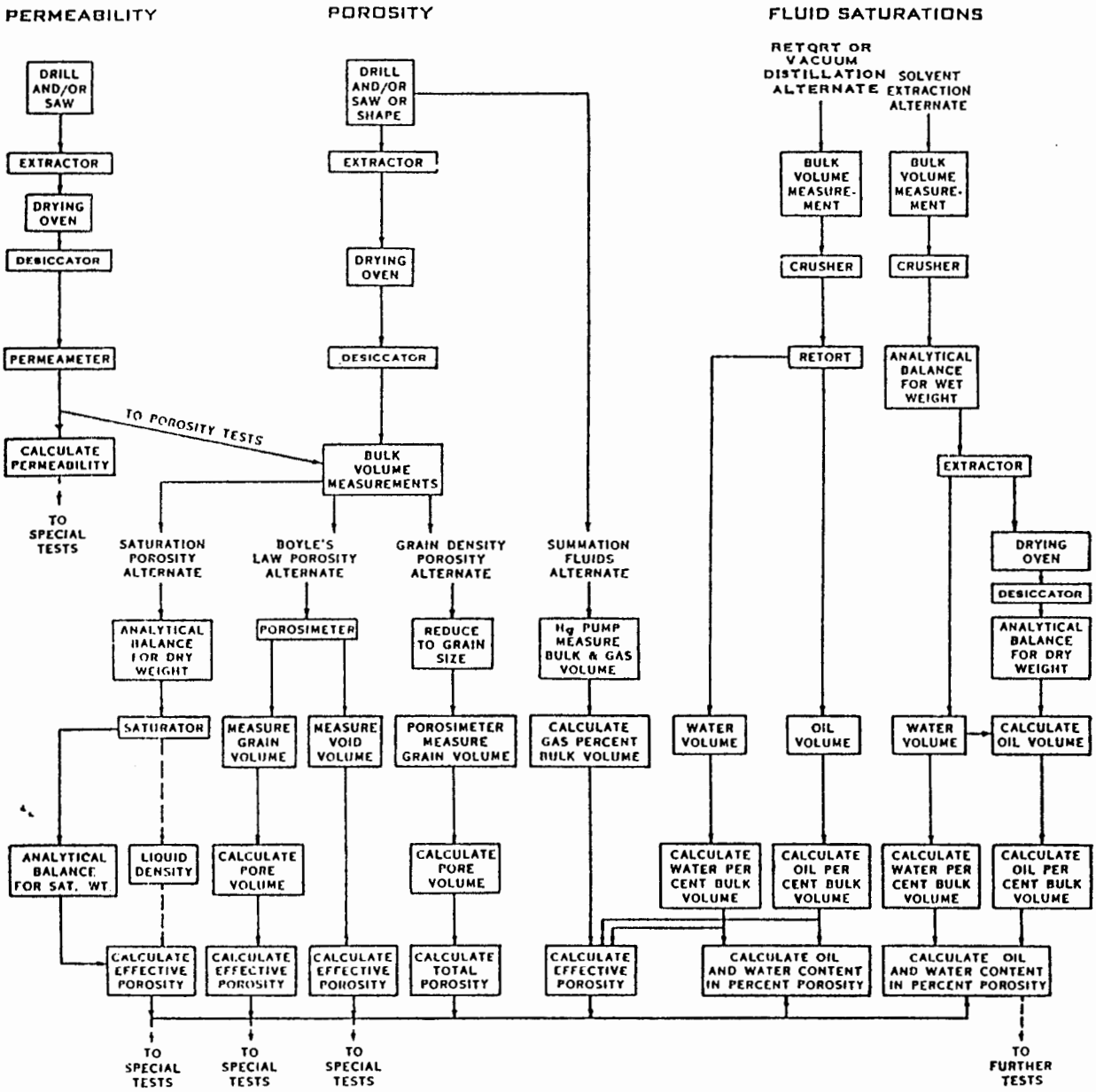
Sidewall cores should be carefully removed from the coring instrument. They should not be broken or squeezed if any core analysis is intended. Sidewall coring barrels should not be washed after being pulled out of the hole until after the cores have been removed. Sidewall samples to be used for core analysis must be delivered to the laboratory in the same state, as nearly as possible, as when removed from the barrel.

Tests show that sidewall samples taken by percussion exhibit changed permeability and porosity as well as grain fracture. Punch samples do not seem to show as much distortion, but sometimes have altered fluid content resulting from mud contamination. Rotary-cut sidewall samples are best for core-analysis testing.

The samples taken from the core barrel should be placed immediately in glass jars or other non-absorbent containers. These jars should be tightly closed and sealed, e.g., by a piece of tape wrapped around the glass-to-metal contact to insure that the core container is air-tight. Such containers should be shipped to the laboratory in suitable boxes to prevent core or glass breakage from rough handling. The samples should remain in the sealed jars until testing is carried out.

3.0 CONVENTIONAL CORE ANALYSIS

CONVENTIONAL CORE-ANALYSIS PROCEDURES



(A schematic flow sheet of the routine core analyses described in Section 3.1.)

3.1 LABORATORY CORE PREPARATION

The preparation of core samples for laboratory analytical procedures must, of necessity, be dependent upon:

a. The data desired on the particular core to be analyzed.

b. The type of rock or formation from which the core was taken.

c. The coring technique involved in cutting and bringing the core to the surface.

For example, if fluid saturation data are required, the core must be carefully and expeditiously handled in the laboratory so that the fluids in the sample remain relatively undisturbed until the analysis has been undertaken. Many formations contain clays which are susceptible to swelling or chemical reaction when contacted with fresh water, thereby altering the basic characteristics (porosity and permeability) of the rock. Therefore, any fluids which contact the samples during cutting and handling of the sample prior to analysis must not in any way damage the sample or displace any of the native fluids in the sample. Prolonged exposure to sunlight, air, or heat will greatly affect the fluid saturations in the sample prior to analysis. It is, therefore, important that the samples be analyzed as soon as the preservation medium has been removed.

3.11 CUTTING OF SAMPLES

The core containers should be opened one at a time and each 1-ft section of core (or as requested) divided into representative portions for the determination of porosity, permeability, and fluid saturation. The portion designated for saturation determination is prepared for immediate analysis by chipping off the periphery—which, in more permeable cores, is severely contaminated by drilling fluid—with a hatchet, hammer, chisel, or knife. If cores are drilled or sawed prior to the saturation determination, the use of any cooling liquid during the cutting may cause both total liquid content or fluid-distribution data to be of doubtful significance. Cylinders and cubes for porosity and permeability determinations are cut with diamond drills and diamond or carborundum saws. The preferred sample sizes are:

a. Cylinders — ¾-in. to 1½-in. OD; minimum length to diameter ratio equals 1.
b. Cubes — ¾-in. minimum.

Usually cylinders are cut parallel to the bedding plane. Some laboratories prefer the use of cubes, as both horizontal and vertical permeabilities can be determined in each cube. Fragile cores may be shaped with a knife.

When cutting a plug, it is common practice to keep the sample wet with a cooling liquid to prevent fine cuttings from plugging the porous surfaces. The use of diesel oil or kerosene rather than water may be preferred as water will cause some types of core materials to swell, causing the sample to become fractured or to disintegrate.

Particular attention must be given by laboratory personnel to the identification of each laboratory sample prepared to assure that each foot of sample received by the laboratory is analyzed.

3.12 CLEANING OF SAMPLES

3.121 Solvents

Prior to the laboratory measurement of porosity and permeability, the original liquids must be completely removed from the core sample. Various solvents used for hydrocarbon-extraction purposes are listed alphabetically.

a. Acetone
b. Benzene
c. Benzene-methylalcohol
d. Carbon tetrachloride
e. Chloroform
f. Ethylene dichloride
g. Hexane
h. Naphtha
i. Tetrachloroethylene
j. Toluene
k. Trichloroethylene
l. Xylene

The particular solvent to be used should be selected in order not to attack, alter, or destroy the structure of the sample. It should be recognized that the solvents in this list may not be complete solvents for all hydrocarbon constituents in natural cores, but they have been widely used for extracting samples for routine analysis. Some will be more suitable than others for specific uses; e.g., chloroform has been found to be excellent for many mid-continent crudes, and toluene has been found useful for asphaltic crudes. Carbon tetrachloride may hydrolyze during extraction, forming hydrochloric acid as a product. When subjected to higher temperatures, it decomposes, liberating phosgene gas and leaving an insoluble material in the core.

Closed-type electrical heaters should be used whenever inflammable solvents are used. Safety precautions such as adequate ventilation of the laboratory, accessibility of fire extinguishers, fire buckets, and safety showers should always be observed. Extraction should be conducted under hoods equipped with forced-draft ventilation.

The various solvents used for extracting core samples can be reclaimed by well-known physical and chemical methods. Such recovery can make practical the use of an expensive solvent, which may be ideally suited for a particular extraction.

Salt can be removed by the use of methyl alcohol or other solvent in which salt is somewhat soluble. The presence of much salt in the cleaned and dried sample may affect the measured and porosity and permeability values. Consequently, core samples containing a formation water with high salinity, may require additional extraction to remove salt.

3.122 Flushing by Direct Pressuring of Solvent

Extraction of hydrocarbons and salt from reservoir rocks can be achieved by injecting one or more solvents into the core sample under pressure at room temperature. The pressures used are dependent upon the ability of fluids to move through the sample and may range from 10 to 1,000 psi. The core samples may be held in a rubber sleeve or suitable core-holding device which will permit the flow of solvent through the matrix of the sample. The volume of solvent required to completely remove hydrocarbons in the core sample is dependent upon: *a*, the nature of the hydrocarbons present in the sample; and *b*, the solvent or solvents used. The core is considered to be clean when the effluent solvent is clear. In some instances, more than one solvent may be required to remove heavy, asphaltic-type crude oils.

3.123 Flushing by Centrifuge[5]

A centrifuge with a specially designed head is used to spray warm, clean solvent (from a still) against the core samples. The centrifugal force causes solvent that contacts the samples to flow through them, thus displacing and extracting the oil (and water). The speed of rotation is varied from a few hundred to several thousand revolutions per minute, depending upon the permeability and degree of consolidation of the core samples being extracted. Samples up to 1½ in. in diameter and 3 in. in length can be successfully extracted by this method. Most common solvents can be used. The apparatus and procedure are described in 3.51.

3.124 Gas-driven Solvent Extraction (U. S. Patent 2,617,719)

In this method of cleaning core samples, the core is subjected to repeated cycles of internal dissolved- or solution-gas drive until the core is cleaned of

residual oil. The remaining solvent and water are removed by means of a drying oven.

When a core from an oil-bearing formation is brought to the surface and depressured, the gas dissolved in the oil comes out of solution and pushes some of the oil and water out of the core. This leaves the core sample with some of the pore space filled with gas at atmospheric pressure. The gas-filled space is the factor which makes it possible to remove the residual oil from the core. The gas-filled space in the core can be almost completely filled with solvent by surrounding the core with a suitable solvent containing a dissolved gas and applying sufficient hydraulic pressure. Under this condition, the solvent mixes with the oil in the core and subsequent depressuring to atmospheric pressure removes some of the residual oil.

If this cycle is repeated a sufficient number of times, the core becomes practically oil-free. The remaining solvent and water are then removed by vaporization. This method will clean any porosity, regardless of the type or complexity. It works in a crack or fissure system as well as in a pure intergranular-type porosity. It is successful in the so-called dead-end or one-opening type of porosity. It should be noted that this process may separate or fracture loosely consolidated core samples during cleaning.

Carbon dioxide gas is excellent because of low fire or explosion hazard and high solubility in most solvents. Some of the solvents which can be used are naphtha, toluene, or mixtures of solvents. With certain types of crude oil, cleaning time may be reduced if the core chamber is heated by a water bath, steam bath, or by electric heaters. One successful application of this method for routine cleaning of cores uses carbon dioxide and toluene at 200 psig with a hydraulic pressure of 1,000 psig. Cycles of approximately 30 min are used. The apparatus and procedure are described in 3.52.

3.125 Distillation-Extraction Method

The usual Soxhlet extraction apparatus, using a solvent or solvents which will dissolve and extract the oil and salt-laden water efficiently and not attack the sample, is suitable for the purpose of cleaning core samples. Extraction can be arranged in a manifold so that the oil and water-laden solvent siphons from each extractor into a common still from which fresh solvent is continuously distilled, condensed, and again distributed to the several extractors.

The cleanliness of the sample is best determined from the color of the solvent which siphons periodically from the extractor. Extraction should be continued until the extract is water-white. A non-luminescence of the extract under fluorescent light is a good criterion of complete extraction of the oil for a given solvent. It should be noted that the complete extraction of certain oils from core samples may require more than one solvent, and the fact that one solvent is water-white after contact with the sample does not necessarily mean that the oil has been completely removed from the sample. Descriptions of suitable apparatus and procedures may be found in most standard reference books on physico-chemical measurements. Details of one apparatus and procedure may be found in 3.55.

3.13 DRYING

Conventional core samples can be dried by:

a. A conventional controlled-temperature oven utilizing a maximum temperature of 240 F. for a minimum of 2 hours.

b. A vacuum controlled-temperature oven utilizing a maximum temperature of 200 F. for a minimum of 2 hours.

Each core sample should be dried until the weight becomes constant.

3.14 PRECAUTIONS

There are a number of precautions which must be observed in the preparation of all types of samples for routine core measurements. These are:

a. Samples containing clays and gypsum must not be dehydrated during preparation. Care must be exercised in drying samples containing hydrated or hydratable materials. In some cases, temperatures lower than those indicated in 3.13 must be used to prevent the dehydration of clays and gypsum.

b. Samples must be protected from erosion by the drip of the clean solvent when utilizing the Soxhlet extraction technique.

c. Care must be exercised in the selection of an extraction technique which does not physically damage samples which are not well-consolidated. The Soxhlet extraction technique is usually more suitable for this type of sample.

d. The usual criterion for sample cleanliness is a clean extract; but it must be recognized that many solvents are not complete solvents for all types of oils.

e. Samples containing heavy asphaltic oils usually require the cycling of more than one solvent.

3.2 FLUID-SATURATION DETERMINATION

Accurate determination of the fluid content and specific fluid saturations of cores is an important element in the interpretation of core-analysis data. Proper care in handling and preservation of the core until analyzed is very necessary to prevent changes in fluid content by drying or contact with water.

Specialized analytical techniques have been developed for the study of core samples of different physical characteristics and different sizes, as obtained by the various methods of coring. Several widely used procedures for determining core fluid saturations provide acceptable data.

3.21 RETORT METHOD AT ATMOSPHERIC PRESSURE

(Use of downdraft retort covered by U. S. Patents 2,282,654 and 2,361,844)

3.211 Principle

In conventional analysis the liquid saturations may be obtained by distillation of a sample at atmospheric pressure. This process is known as the retort method. Liquids in the sample are vaporized in the heating chamber, the vapors are condensed in a water condenser, and the recovered liquids are collected in calibrated receiving tubes. Representative pieces of core with an aggregate weight of between 100 and 175 grams are normally used in each retort sample.

3.212 Data

By using an oil correction curve, the accuracy of the oil value obtained by the retort method is within ±5 percent, and the reproducibility is within ±2 percent of the volumes measured. The accuracy of the water value obtained by this method is within ±2.5 percent of the volume measured. The oil and uncombined water distilled from each sample are calculated as percentages of bulk volume, using the total weight of the sample and the natural density determined on an adjacent piece of sample. The retort is a rapid method for measuring liquid content and is accurate enough for most applications of data.

3.213 Advantages

a. Liquid content is determined on large amounts of core sample.

b. The volume of each liquid recovered is obtained by direct measurement.

c. Possible error from the weight of salt deposited from water contained in the sample is eliminated.

d. Possible error from loss of sand grains in handling is eliminated.

e. Oil content is measured directly; whereas, in extraction methods, oil content is calculated by difference between relatively large numbers, where errors such as pointed out in c. and d. could cause large errors in calculated oil saturation.

3.214 Limitations

a. Water-calibration data for each formation are necessary for accurate results.

b. Accuracy of water-saturation data for samples containing clay materials is less because of difficulty in establishing correct retort temperature or time to remove uncombined water only.

c. Oil-recovery correction curve is required.

d. Two separate pieces of core are used to obtain the data.

The details of the apparatus and procedure may be found in 3.53.

3.22 VACUUM DISTILLATION METHOD

3.221 Principle

The vacuum distillation method for determining the oil and water content of a core consists of heating the core in an evacuated chamber, condensing the liberated vapors, and recording the volume of the recovered liquids. The procedure is applicable to cores of any size, but the apparatus described herein is designed for distillation of liquids from core samples approximately 1 in. in diameter and a maximum of 4 in. in length.

If the oil originally in the core contained components which were not distilled, a correction must be applied to the volume of the oil collected in order to estimate the volume of oil originally in the core. The correction factor may be determined experimentally by the distillation of a known volume of the oil.

3.222 Advantages

a. Oil and water content are measured directly and independently of each other.

b. Water content can be determined accurately with this technique if the core minerals are stable up to 446 F. (230 C.).

c. If the minerals are stable up to the temperatures used, the sample is not destroyed.

d. Oil-content determinations are very accurate where high-gravity crude oils are being distilled.

3.223 Limitations

a. Oil-content correction data must be determined for any oil other than high-gravity crude oils.

b. Low-gravity crude oil is difficult to distill at the temperatures used.

c. Close attention is often required during the distillation.

The apparatus and procedures are described in 3.54.

3.23 DISTILLATION-EXTRACTION METHOD

3.231 Principle

The distillation-extraction method of determining fluid saturations of cores depends upon distilling water from the sample, condensing it, and accumulating it in a calibrated receiver. The oil is removed by solvent extraction and is determined as the difference between the weight loss during the distillation-extraction operation and the weight of the accumulated water. The solvent used for extracting the oil normally has a boiling point above that of water, so that the water within the core is distilled out as it is heated by the solvent vapor. The solvent vapor condenses and continually drips on the core sample to extract the oil.

3.232 Data

The liqiud content of a core sample shall be reported to the nearest percent of the pore space, e.g., 22 percent oil and 43 percent water.

3.233 Advantages

a. The procedure is simple and requires little attention during the distillation.

b. Very accurate water-content determinations can be made.

c. Relatively low temperatures are normally used and the decomposition of minerals is minimized.

3.234 Limitations

a. Gain of water affects calculated oil content.

b. Loss of sand grains affects calculated oil content.

c. Proper drying temperature is critical because high heat causes loss of clay water, and low heat leaves residual solvent in the core. Both of these factors affect the calculated oil content.

Details of the apparatus and procedure may be found in 3.55.

3.3 POROSITY DETERMINATION

Porosity, which is defined as the ratio of the void-space volume to the bulk volume of a material, is an intrinsic property of all reservoir rocks. The amount of void space which can be occupied by hydrocarbons or water in a reservoir must be known for any intelligent estimate of the economics of oil or gas production. The precision with which porosity can be determined is largely a function of the methods used in its measurements. However, the results of porosity measurements by whatever methods are now in use cannot be expected to correspond exactly to *in situ* conditions owing to: *a*, possible relaxation of cores upon release of overburden and fluid pressures; and *b*, the hydraulic and mechanical actions of the coring process. Several logging tools using either electrical, nuclear, density, or sonic methods are used for porosity resolution around the well bore. The measurements obtained are, of course, calibrated against porosities measured at surface conditions and the relationships developed apply only to those surface conditions.

In moderate- to high-porosity rocks, most errors introduced in measured porosity values (unless extreme) either by method used, relaxation, or hydraulic or mechanical action are not of prime concern, since they have a relatively small effect percentagewise on the volumetrics of the reservoir. This is not true in low-porosity rocks, however, since a relatively small error here has a very appreciable effect percentagewise on the calculated pore volume.

In the laboratory usually one or two types of porosity are measured, viz., effective porosity or total porosity. Effective porosity, which is a measurement of the inter-connected voids, is derived from either bulk volume and apparent grain volume determinations or a direct measurement of the inter-connected void space. The measured volume of the inter-connected void space may vary with the method used. Total porosity, as the term implies, is a measure of the total void space in the rock sample and is determined by bulk-volume, dry-weight, and grain-density measurements. Inasmuch as some porosity logging devices respond to total porosity *in situ*, calibration of the response of those devices against laboratory total porosity should be preferable to calibration against effective porosity—possibly measured under a variety of conditions. Again, in moderate- to high-porosity rocks there is little significant difference between effective and total porosities since in such rocks most pores are well inter-connected. In low-porosity rocks, however, a very appreciable and significant difference sometimes is observed as a result of the restricted inter-connection of the pores.

Porosity, measured in a formation sample containing inter-granular clays, is subject to appreciable error regardless of porosity range. This error may be a result of shrinking of clays during the analysis, chemical changes within the clay, or flushing of the clay particles during coring operations. Very special handling and specific techniques should be developed for analyzing such formations.

Another facet of porosity measurement, which in fact applies to the entire field of core analysis, is the selection of conventional analysis vs. full-diameter analysis. The decision as to which type should be used would ideally be based entirely upon the homogeneity of the formation being analyzed. Most sandstones are sufficiently homogeneous that a small sample can be considered representative of the analysis increment. On the other hand, when the formation is heterogeneous as to pore structure or lithology, such as in vugular or fractured carbonates or thinly laminated sands and shale, full-diameter core techniques are more applicable. Therefore, the size of sample required to adequately represent the pore structure and lithology of the analysis increment should control the type of analysis used.

3.31 BULK-VOLUME MEASUREMENT

A measure of the bulk volume of a rock sample is required to determine the porosity of that sample. Bulk volume can be determined by several methods. The techniques included are: *a*, liquid displacement; *b*, caliper measurements; *c*, buoyancy; and *d*, grain density. Precautions to avoid trapping air around or under the sample, particularly if an irregular-shaped piece is selected, should always be taken when using the liquid displacement or buoyancy technique.

The sample selected for the porosity measurement should preferably be 10 to 20 cc in bulk volume. Normal sample shape and size is either: *a*, a right cylinder, ¾-in to 1½-in. OD, with length of at least 1 in.; or *b*, a cube of about ¾-in. side length. Irregular shapes may be used with proper precautions if samples of regular dimensions cannot be obtained.

3.311 Mercury Displacement

3.3111 Principle

A dried core sample is immersed in mercury in a calibrated pycnometer. The volume of mercury displaced by the sample is weighed. The measurement by weight can be repeated within ±0.02 cc if no air is trapped by the sample and the temperature remains constant. The measurement by volume can be repeated to ±0.05 cc.

3.3112 Advantages

a. Samples can be used for subsequent tests if no mercury penetration occurs.

b. The method is accurate if careful technique is used and precise measurements are made.

3.3113 Limitations

a. This method is slightly more time-consuming than some others for determining bulk volume.

b. Trapping air around the samples will create errors.

c. Samples with a vugular surface must be sealed by coating or filling the vugs to prevent mercury penetration. The volume of any coating must be subtracted from the total bulk volume measured. The apparatus and procedure are described in 3.56.

3.312 Bulk-volume Meter

3.3121 Principle

The bulk volume of core samples is measured by direct displacement into an inclined calibrated tube with a suitable scale. The liquid is displaced into the inclined tube by submerging the core sample under mercury in an adjacent, connected chamber. The apparatus is illustrated in Fig. 3.57F1.

If the meter is properly calibrated, readings should be reproducible within ±0.05 cc.

3.3122 Advantages

a. The equipment occupies a small space, is portable, and can be designed to accommodate small or large cores.

b. Calibration and operation are simple and quick.

3.3123 Limitations

a. Friable samples may contaminate the mercury and induce a small amount of error.

b. Vugular samples may retain small amounts of mercury which, again, induces error.

c. Trapping air around the sample will create errors.

The apparatus and procedure are described in 3.57.

3.313 Mercury Pump

3.3131 Principle

Mercury is pumped around the core sample which is enclosed in a calibrated steel pycnometer. The steel pycnometer is an integral part of the pump, which consists of a measuring cylinder (filled with mercury) and a metering plunger. A scale and dial arrangement, which is graduated to 0.01 cc, permits a reading of the movement of the plunger. The pycnometer is closed by a top which contains a small recessed opening. With no sample in the apparatus, the top is placed on the pycnometer and the pump plunger is advanced until a small bead of mercury appears at the opening of the top. The pump scale is then set on zero. After backing off the plunger to lower the mercury in the pycnometer, the sample is inserted, and the plunger is again advanced until a small bead of mercury appears at the opening. The reading on the scale and vernier arrangement is taken, and the difference between this reading and the first reading (instrument zero) is the bulk volume of the sample.

The measurement can be reproduced to ±0.01 cc if the pump is rezeroed for each sample.

3.3132 Advantage

a. This procedure allows very rapid measurements to be made.

3.3133 Limitations

a. Trapping air around the sample will create errors.

b. Vuggy samples or extremely high-permeability samples may be penetrated by the mercury which will result in low values.

The apparatus and procedure are described in 3.5.14.

3.314 Caliper

3.3141 Principle

Samples which are right cylinders or other regular shapes may be calipered to obtain bulk volume. A micrometer or vernier caliper, which can be read to the nearest 0.01 cm, can be used.

The length and diameter of the cylinder, or the sides of the cube, are measured several times in each dimension to define any irregularities in the shape. Small deviations in the shape may be averaged out. The cross-sectional area of the sample is calculated from the diameter or the side width and breadth measurements on shaped pieces and multiplied by the length to obtain bulk volume.

Volumes can be repeated to ±0.15 cc.

3.3142 Advantages

a. The sample may be used for other tests.

b. The procedure is rapid.

c. Accurate values can be obtained if samples are true regular shapes.

3.3143 Limitation

a. Samples with irregular shapes cannot be measured by this method.

3.315 Buoyancy

3.3151 Principle

The sample is saturated with a liquid of known density, such as kerosene. Excess liquid is removed from the sample and the saturated sample is weighed. A beaker is filled with the saturating liquid, and the saturated sample is submerged in it. The sample is supported by a fine wire attached to the stirrup of the balance and a submerged weight measurement is made. The net submerged weight is obtained by subtracting the tare weight from the measured submerged weight. The initial weight of the saturated sample in air minus the weight when submerged, divided by the density of the saturating liquid yields bulk volume.

3.3152 Advantages

a. Accurate values can be attained if proper technique is used.

b. The sample is saturated with liquid for other tests which may be desired.

3.3153 Limitations

a. Samples must be completely saturated to eliminate buoyancy effects.

b. The liquid must be removed for some other tests which may be desired.

c. Cores containing vugs cannot be measured by this method.

d. Liquids which may leach the sample or cause swelling of the matrix cannot be used.

The apparatus and procedure are described as part of 3.5.13.

3.32 PORE-VOLUME MEASUREMENT

The pore-volume measurement may be made either as *a*, total pore volume on a crushed sample; or as *b*, effective pore volume on the uncrushed core.

3.321 Total Pore Volume

The total pore volume is the difference between the bulk volume and the grain volume. An accurate grain-density measurement is necessary for calculating the grain volume from the weight of the sample. In heterogeneous core samples, great care should be taken to obtain representative portions of the core for grain-density measurements.

3.3211 Dry Method for Grain Density

3.32111 Principle

The weighed sample is placed in a Boyle's Law porosimeter used to measure grain volume. Its grain density is determined as described in 3.58. The grain density is used to calculate the percent total porosity of the original saturation sample by subtracting the volume of the sand grains from the bulk volume. The procedure should be reproducible to within ±0.5 of 1 porosity percent, provided the bulk volume measurement is equally precise.

3.32112 Advantages

a. This method is faster than the "wet method".

b. No liquids are involved in the measurement and the sample can be retained for future reference.

c. The saturation sample may be used for this test.

d. The equipment is easy to operate.

e. The procedure has excellent repeatability.

3.32113 Limitations

a. The accuracy will be affected by shaliness in the sample.

b. The grain density obtained is not a direct measurement of the entire sample.

For further details, see 3.58.

3.3212 Wet Method for Grain Density

3.32121 Principle

A portion of a weighed crushed extraction sample (bulk volume is measured prior to pulverizing) is used to displace an equivalent volume of liquid—e.g., toluene—in a volumetric flash. This displaced volume

is determined; and knowing the weight of the core sample, the grain density may be calculated from the relationship:

Density = weight of sample/volume of sample (1)

The reproducibility should be the same as that for the dry method (3.3211).

3.32122 Advantage

a. Many samples can be handled at one time.

3.32123 Limitations

a. The grain density obtained is not a direct measurement of the entire sample.

b. If the wetting action is not effective, some error may be introduced.

c. The liquid used (particularly if it is not highly refined and perhaps even then) may react with shale or other minerals present in the rock.

For further details see 3.59.

3.322 Effective Pore Volume

The measurement of the effective porosity of reservoir rocks can be made by determining the volume of sand grains in a core sample by a procedure depending on Boyle's Law or by procedures based on measuring the void volume.

3.3221 Grain-volume Measurement

3.32211 Boyle's Law Single-cell Method

3.322111 Principle

The effective pore volume is measured by compressing a known volume of gas at a known pressure into a core which was originally at atmospheric pressure. The sand grain volume and pore volume are calculated from these pressure measurements. The grain volume is defined as the difference between the total gas space of the void volume plus the annulus and the calibrated volume of the core holder. The void volume of the core is obtained by subtracting the measured grain volume from the bulk volume. This void volume is the effective pore volume of the core.

Grain-volume measurements should be reproducible within ±0.01 cc using Boyle's Law single-cell units.

3.322112 Advantages

a. The test specimen is not damaged in any way and can be used for other measurements.

b. The operation is quick, simple, and has excellent repeatability.

3.322113 Limitations

a. For good accuracy, extremely careful calibration is required.

b. Changes for temperature and barometric pressure must be corrected.

c. The measured value may be higher than the true porosity value if gases absorb on the core surfaces. The use of helium will minimize this possibility.

For apparatus and procedural details of one Boyle's Law single-cell unit see 3.5.10.

3.32212 Boyle's Law Double-cell Method

3.322121 Principle

The sand grain volume is measured in an apparatus consisting of two connected chambers. The core sample is placed in one chamber and the gas pressure in this chamber is adjusted to some known value. The gas in the second chamber is adjusted to some different known pressure. The pressure is equalized and measured and the final volume is known. From these data and Boyle's Law, the volume occupied by the sand grains is calculated. The pore volume is the difference between the grain volume and the bulk volume.

Three modifications for Boyle's Law double-cell apparatus and procedure are described in 3.5.11. Modification A gives grain-volume values from 4.0 to 13.5 cc with errors that continually decrease in this range from ±1.1 percent to ±0.02 percent of the calculated pore volume measured. Other users also report this order of accuracy. Any of the Boyle's Law double-cell porosimeters discussed should be capable of this accuracy when properly built and operated.

3.322122 Advantages and Limitations

The same points apply here as for Boyle's Law single-cell (3.322112 and 3.322113).

3.3222 Void-volume Measurement

3.32221 Washburn-Bunting Method[6]

3.322211 Principle

The effective pore volume is measured by expanding the pore gas and measuring its amount. This method employs simple equipment (Fig. 3.5.12F1) and applies best to well-consolidated cores. The bulk volume of the core must be measured independently.

Measurements are reproducible to ±1.0 porosity percent in the porosity range of 8 to 40 percent.

3.322212 Advantage

a. A simple, rapid operation.

3.322213 Limitations

a. Repeated expansions are necessary for samples with very low porosities and permeabilities.

b. When applied to friable or highly permeable cores, this method gives rise to troublesome mercury penetration into the cores, rendering them useless for further tests.

c. This apparatus is susceptible to leakage around the stopcock.

The apparatus and procedure are described in 3.5.12.

3.32222 Summation of Fluids

(U. S. Patent No. 2,345,535)

3.322221 Principle

The pore spaces of core samples normally contain some gas, as a result of the liberation and expansion of dissolved gas as the core and its reservoir-fluid content are brought to the surface. The remaining pore space is filled with liquid, either water or both oil and water. One method of obtaining porosity involves determining independently the gas, oil, and water contents of the core, each being measured as a percentage of the bulk volume of the core. The sum of these three percentages is equal to porosity. This procedure requires that the core sample be divided into two portions, care being taken to select adjacent portions with similar characteristics. One portion, a single piece of 25- to 40-gram size, is used to determine the gas content by injecting mercury into the sample at 750 or 1,000 psi. The second portion, which may be composed of several pieces with a total weight of 100 to 175 grams, is used to determine the oil and water content.

The porosity determination is normally within ±0.5 porosity percent.

3.322222 Advantages

a. Measurements are made on large amounts of core sample.

b. Volume of each fluid is obtained by direct measurement.

c. No error arises as a result of salt deposition from water content of sample or loss of sand grains in handling.

3.322223 Limitations

a. Some error may be introduced by inability to account entirely for water of hydration.

b. Two separate pieces of core are used to obtain the data.

The apparatus and procedure are described in 3.53 and 5.512.

3.32223 Hydrocarbon Resaturation

3.322231 Principle

The measurement of effective porosity by the hydrocarbon liquid resaturation technique involves the gravimetric determination of pore volume (and bulk volume) by obtaining: *a*, the weight of the core sample clean and dry; *b*, the weight of the sample saturated with a liquid of known density; and *c*, the weight of the saturated sample submerged in the liquid of known density.

The determination of effective porosity by the hydrocarbon resaturation technique must of necessity be limited to samples which can be saturated and the saturated weight successfully determined. Experience has shown that the porosity of vugular and cavernous limestone cores cannot be accurately determined by this method because of the loss of liquid during the weighing process.

This method should give effective porosity within ±0.5 porosity percent.

3.322232 Advantages

a. Many samples can be handled at one time.
b. The procedure is basically very accurate.

3.322233 Limitations

a. The procedure is slow in regard to total elapsed time of measurement. The amount of "operator time" is reduced from some of the procedures for other methods.

b. Special precautions are necessary to insure complete saturation.

The apparatus and procedure are described in 3.5.13.

3.32224 Mercury Pump Method
(U. S. Patent No. 2,874,565)

3.322241 Principle

According to Boyle's Law of isothermal expansion, when the pressure on a gas is reduced to half the original pressure, the volume of the gas is doubled. The mercury pump, which may be adapted to utilize this principle, provides a fast and accurate procedure for measuring the porosity of samples that have been extracted and dried.

Porosity determinations can be made by this procedure with errors not exceeding ±0.4 porosity percent.

3.322242 Advantages and Limitations

The advantages and limitations which apply to the Boyle's Law single-cell method apply here as well (see 3.32211).

The description of the apparatus and procedural details may be found in 3.5.14.

3.4 GAS PERMEABILITY DETERMINATION

Permeability is a measure of the ability of a porous sample to transmit fluids. Either gases or liquids are used as fluids in permeability measurements. However, liquid permeabilities are not considered routine because of such factors as interaction between rock constituents and liquids and control of bacterial action. Therefore, only gas permeability will be considered in this manual of routine practices.

The permeability measurement will be standardized using dry air as the gas. If air permeabilities reported for routine core analysis have been corrected, using a standard table of Klinkenberg corrections,[7] then this should be noted specifically in the report. This corrects the gas permeability of a porous medium to the corresponding value for a non-reacting liquid. This correction is most important for samples with low permeability. The direction parallel to the bedding plane will be standardized as the horizontal permeability. Any measurements in other directions—i.e., vertical—should be so specified and the details described.

Samples of hard, consolidated cores having uniform properties are cut to shape and their permeability measured directly by conventional methods. A proper frequency of samples must be measured to obtain a representative permeability for the rock. Friable, soft, or shaly cores may require support to prevent distortion or alteration during testing for permeability. Such samples may be supported by mounting in a suitable potting plastic or optical pitch. Friable or soft samples supported in this way are then run according to the conventional core-analysis scheme.

Vugular, fractured, or crystalline carbonate rock, fractured and recemented cherts, and laminated shaly rocks are often handled by full-diameter methods to obtain a more representative permeability value for the interval analyzed.

3.41 GENERAL PROCEDURE

The sample used for the permeability measurements may be either the consolidated piece used previously for saturation and porosity determination, or a separate sample. If the sample has been used for saturation measurements, it is already clean. Otherwise it must be extracted and dried to remove the oil and water as described in the section on laboratory core preparation (see 3.1). Precautions to remove salt may be necessary if the interstitial water was very saline.

An air permeameter consists of the following major units (see schematic drawing, Fig. 3.5.15F1, of 3.5.15):

a. A source of dry air.
b. Pressure regulator.
c. Inlet-pressure measuring device.
d. Core holder. (Hassler and Fancher-type holders are used for conventional core analysis.)
e. Outlet-pressure measuring device.
f. A flow-rate metering device.

A standard permeameter should be designed to measure air permeabilities within a range of 0.1 to 5,000 md.

Because of the sensitivity of the permeability measurement to minor changes in sand lithology, measured values from adjacent pieces in an apparently homogeneous sand may not check within ±5 percent. For this reason any given measurement may not exactly characterize a given sand, and dictates the use of not more than two significant figures in reporting permeabilities.

Observation of the precautions listed in 3.5.15.3 and care in operating the equipment described there can lead to a reproducibility of about ±2 percent for most samples with permeabilities of 0.1 md or more.

3.5 DESCRIPTION OF PROCEDURES FOR ANALYSES

3.51 SOLVENT FLUSHING BY CENTRIFUGE[5]

3.511 Apparatus

The apparatus consists of two major parts, viz., a centrifuge and a solvent still.

The special centrifuge head required for this work may be put in certain types of commercially available centrifuges, or it may be installed in specially designed instruments. The head has a small-diameter circular trough at the center into which clean, warm solvent flows. The solvent is forced from the trough through small radial holes by centrifugal action. The holes are countersunk at the outward ends to cause the solvent to be expelled as a fine mist toward the outside ring of the head. The holes are spaced horizontally and vertically in a pattern to give good coverage to the core samples. The outer ring of the head holds the samples in position. Holes in the outer ring allow fluids to escape from the head. The chamber in which the head operates serves to collect the solvent and extracted fluids which then drain by gravity to the solvent still. The centrifuge chamber should be vapor-tight.

The boiler section of the still is normally of large capacity (about 10 liters). It should be heated with approximately 1,000 watts in order to supply a sufficient volume of clean solvent to the centrifuge. The heaters may be either external or immersion type. The boilers are normally well-insulated to improve the efficiency of the still. The condensing jacket and condensate trap are built as in a Soxhlet extractor so that distilled solvent may be collected until it fills a siphon line, at which time the collected clean solvent siphons into the centrifuge and a new cycle is started. Heat from the boiling solvent keeps the solvent in the condensate trap warm until it is "dumped" into the centrifuge. A siphon bypass line will allow the continuous flow of solvent into the centrifuge, if desired.

The still is normally of such a height and is placed in relation to the centrifuge so that clean solvent may flow by gravity to the centrifuge, and dirty solvent may flow by gravity to the still boiler.

The centrifuge head and the still must be made of materials which will not react with the solvents used. Stainless steel is often used, but aluminum can be used in many applications. The still and centrifuge should be operated in an enclosed vented cabinet or hood.

3.512 Procedure

a. Turn on the solvent still heater and cooling-jacket water.

b. Place a strip of felt inside the outer ring of the centrifuge head. This strip is used to eliminate the "end effects" in the core samples and to cushion the edges of the core samples as they are forced against the rim of the rotating head.

c. Place one end of the core samples against the felt strip. Samples of like size and density should be placed opposite each other in the head in order to approach as nearly as possible balanced weight in the head. Visual observation will normally be sufficient to match samples for placement opposite each other. Weighing the samples is usually unnecessary because near-perfect balance is not required in the centrifuge. The centrifuges in use in this application have heavy flywheels or weight-balancing devices to compensate for slight unbalances in the load.

d. If the centrifuge is not loaded to capacity, distribute the samples around the head in order to distribute the load. The conditions of the foregoing step should still be observed. (A felt strip is sometimes placed around the inside ends of the samples to distribute the solvent.)

e. Close the centrifuge.

f. When the still starts to cycle solvent, start the centrifuge. Adjust the speed control to obtain the desired centrifuge speed. Slow speeds should be used for poorly consolidated material with little structural strength, and high speeds should be used for hard samples. Average speed should be about 3,000 rpm.

g. Centrifuge the samples until extraction is complete. A glass bowl or section in the solvent drain line allows a quick check of the cleanliness of the used solvent and thus a check on the degree of extraction attained. Normally ½ hour extraction time is sufficient to clean samples on which accurate air permeability measurements are desired. An extraction time of 2 hours is normally sufficient for any purpose.

h. Open a bypass valve to allow distilled solvent to return to the still boiler without going through the centrifuge.

i. Run the centrifuge without solvent for several minutes to partially dry the core samples.

j. Stop the centrifuge, and remove the core samples for oven drying.

3.52 GAS-DRIVEN SOLVENT EXTRACTION (U. S. Patent 2,617,719)

3.521 Apparatus

Fig. 3.52F1 is a diagrammatic sketch of one type of apparatus which is used to apply this cleaning method. It consists of a core chamber, a hydraulic pump, a solvent reservoir, and other miscellaneous items such as pressure gages and valves. Used solvent can be recovered, if necessary, by use of an auxiliary boiler and tower.

3.522 Procedure

The cores are placed in the core chamber through the open end. A cap containing an O-ring is screwed in place and the chamber pressured with gas to a pressure equal to the pressure of the gas dissolved in the solvent. The gas in the chamber is then displaced at constant pressure by the solvent-gas mixture. After the chamber is filled with the mixture, it

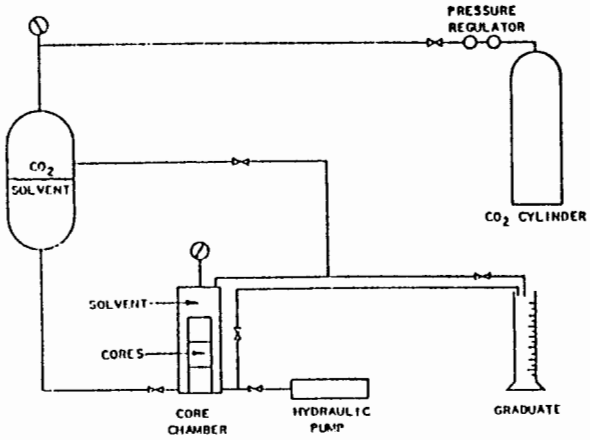


FIG. 3.52F1—SKETCH OF ONE TYPE OF APPARATUS USED TO APPLY CLEANING METHOD

is pressured by means of the hydraulic pump to approximately four or five times the solvent gas pressure. When liquid flow into the cores ceases, the core chamber is depressured rapidly to atmospheric pressure and the cores left submerged in the solvent until most of the gas has flowed from the cores. The solvent is then drained from the chamber and the cycle repeated.

3.523 Data

Data showing the number of cycles necessary to clean full-diameter cores for 4 different types of formations are presented in Fig. 4.51F1, which shows a plot of cleaning cycles vs. porosity for an intergranular-type lime, a fractured lime, a relatively clean sand, and a shaly sand. The core samples reported here were cleaned and dried and the porosity determined. They were then subjected to additional cleaning cycles and dried each time until the pore volume showed no increase. Fewer cycles may be required to clean corresponding conventional core samples. Additional discussion may be found in 4.122.

Consideration of the type of crude in the sample is important in determining the number of cycles necessary for cleaning. In any one type of porosity, a low-gravity asphaltic crude will require more cleaning cycles than a high-gravity crude.

3.53 RETORT METHOD AT ATMOSPHERIC PRESSURE

(Use of downdraft retort covered by U. S. Patents No. 2,282,654 and No. 2,361,844)

3.531 Apparatus

A single-unit type of retort is shown in Fig. 3.53F1. The sample is contained in a stainless-steel cup with a tight-fitting, screw-on top. The sample container cup is placed in an insulated electric heater. The outlet stem of the cup makes a vapor-tight seal with the top of the condensing tube. The condensing tube is fitted with an air-fin cooling section, and a chamber is provided for cooling water around a portion of the tube. A calibrated glass receiving tube collects the liquids.

A modified apparatus consists of an insulated oven made to accommodate several sample cups simultaneously, as shown in Fig. 3.53F2. The oven is heated with continuous wire or by rod-type heating elements, and the sample cups are arranged in the oven in such a manner that an equal amount of heat is supplied to each. The temperature of the oven may be controlled at any temperature up to 1,200 F. The outlet stem of each cup makes a vapor-tight seal with the top of the condensing tube. The condensing tube is a straight tubular condenser and is surrounded by a water bath beneath the oven section. A calibrated glass receiving tube collects the liquids from each condensing tube.

3.532 Procedure

When using the multiple-sample retort oven type, the procedure for obtaining the fluid saturations is as follows: A crushed core sample, weighed accurately and comprising 100 to 175 grams, is put into each sample cup and the cups are placed in the retort oven. The temperature control on the retort is set to a predetermined temperature. To determine the temperature required to retort the uncombined water from samples of a specific formation, a calibration graph of temperature vs. water recovery is plotted, as in Fig. 3.53F3. The first plateau on this curve is taken

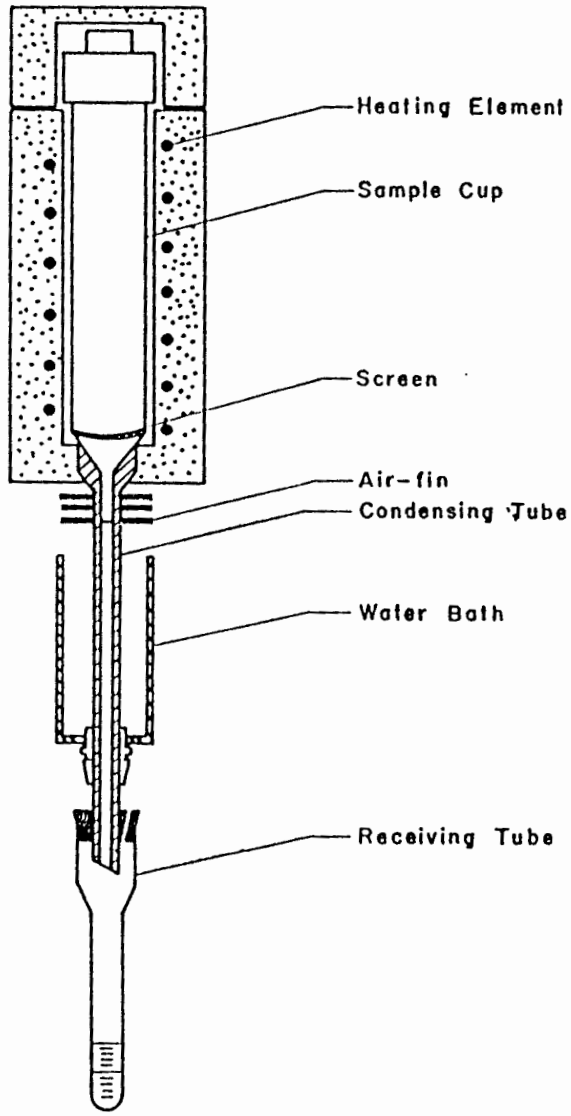


FIG. 3.53F1—OVEN RETORT—ATMOSPHERIC PRESSURE

as the temperature at which the uncombined water will be completely removed. Water removed at higher temperatures may result from the dehydration of hydratable minerals. The predetermined temperature setting used in the procedure is taken as the temperature value just above the plateau of this curve. *It is necessary to determine the proper temperature for each formation.* The temperature of the oven at the time the sample cups are inserted is not critical, provided it is below the predetermined temperature. After reaching the set temperature level, the sample is heated for approximately 20 min to vaporize the uncombined water. The water reading obtained is recorded.

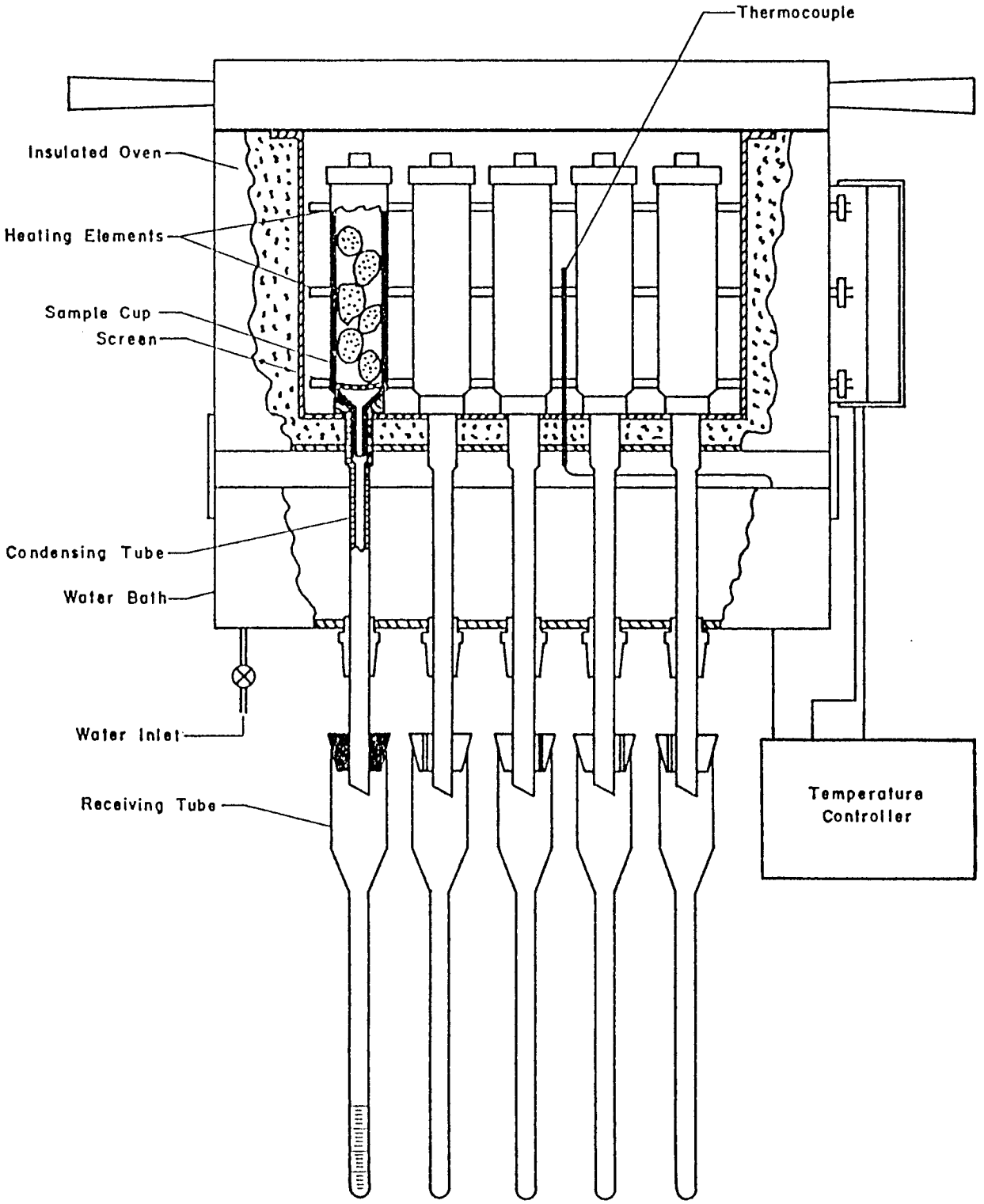


FIG. 3.53F2—OVEN RETORT—ATMOSPHERIC PRESSURE

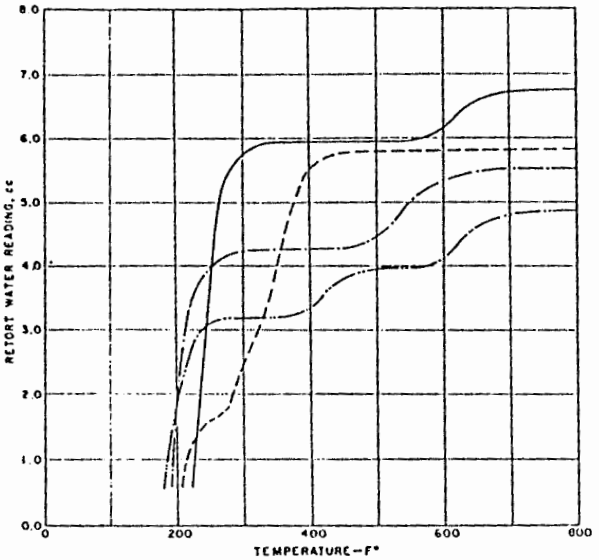


FIG. 3.53F3—WATER CALIBRATION CURVES

After the uncombined water reading is taken, the condensing water bath is drained to allow the condensing tubes to warm. The temperature within the retort is then raised to 1,200 F. to vaporize the heavier oil fractions. After 20 to 30 min of heating the sample at 1,200 F., the heater is turned off and the recovered oil volume is recorded. A correction is applied to the volume of oil collected in order to compensate for vapor losses, coking, and cracking of the oil. This correction is derived empirically from calibration tests made on each type of formation oil. (One example is shown in Fig. 3.53F4.)

Fig. 3.53F5 shows examples of water-distillation calibration curves obtained on different types of formations by an alternate procedure. The retorts are loaded and heat is applied continuously (without temperature control). The volume of water distilled, condensed, and recovered from the sample is plotted vs. the length of time of retorting. The first plateau, or the region from 12 to 20 min in Fig. 3.53F5, indicates removal of all uncombined water. The water reading taken on this plateau is recorded as free water. Curves of this type should be developed for each formation encountered.

3.533 Determination of Natural Density and Gas Content

The bulk volume and gas content of a representative, accurately weighed sample of 25 to 40 grams are determined in a specially adapted mercury pump. The pump shown in Fig. 3.5.14F1 can be used, or one similar to it but without the high-pressure valve or vacuum gage. The sample—still in its natural condition—is placed in the chamber of the volumetric mercury pump, and the bulk volume is measured to 0.01 cc by displacement of mercury. The sample weight is divided by bulk volume to obtain natural density. The needle valve in the cap of the sample chamber is closed and mercury is injected into the sample at 750 or 1,000 psi. The volume of mercury injected into the sample, measured to 0.01 cc, is considered a measure of the gas content. Gas volume is divided by the measured bulk volume to obtain the gas saturation expressed as a percentage of bulk volume.

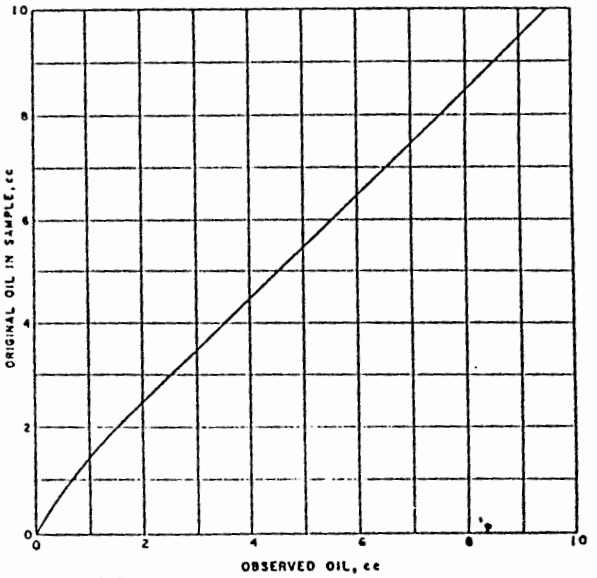


FIG. 3.53F4—OIL CALIBRATION CONVENTIONAL RETORT CUP

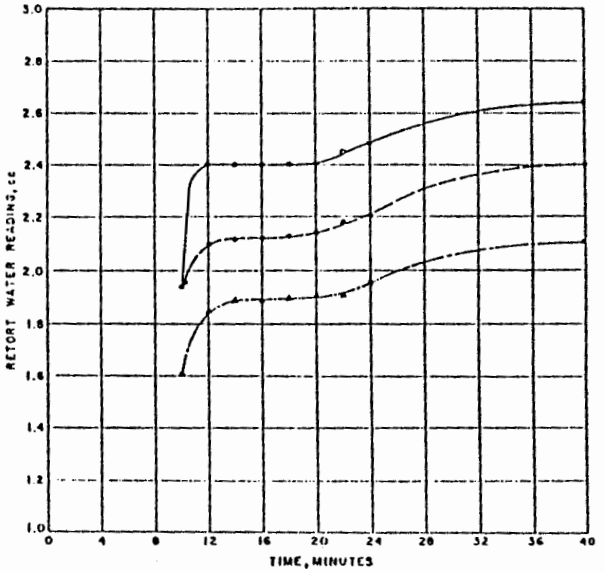


FIG. 3.53F5—WATER CALIBRATION CURVES

3.54 VACUUM DISTILLATION METHOD

3.541 Apparatus

The apparatus consists of an individual heating chamber, a calibrated condenser-collection tube, a vacuum source and manifold, and a liquid nitrogen container.

Fig. 3.54F1 shows the core heating chamber and vapor-condenser system. The glass chamber is encased in a 90-watt 115-volt asbestos-covered heating mantle. Current is supplied to the heating coils from a 110-volt a-c supply through a variable voltage transformer. Glass core supports are provided near the base of the chamber. The top of the chamber

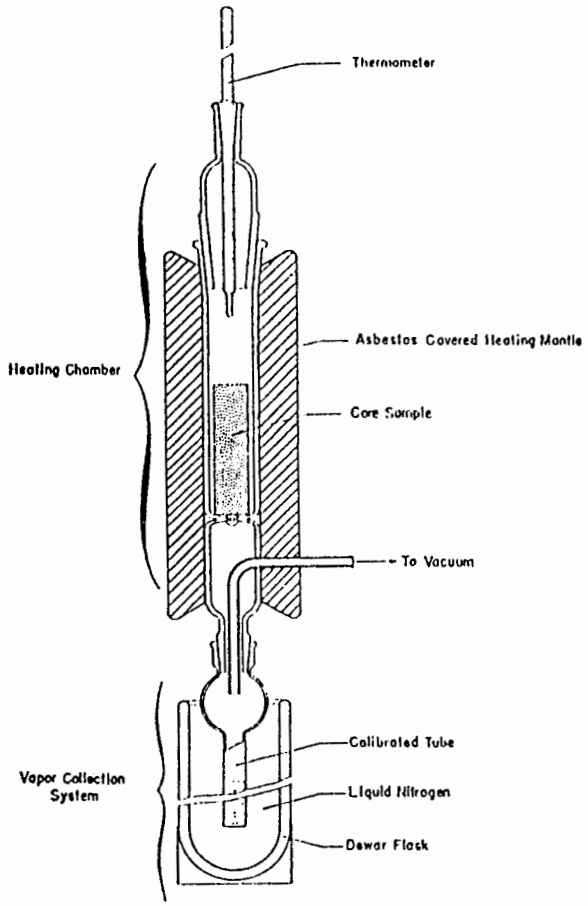


FIG. 3.54F1—CORE HEATING CHAMBER AND PRODUCT RECOVERY SYSTEM

is closed with a thermometer adapter. The temperature in the chamber is measured with a thermometer equipped with a ground-glass joint which permits it to make a vapor-tight seal in the thermometer adapter; a 10-360 C. thermometer (50-680 F.) with a 100-mm immersion length is commonly used. The bottom of the chamber is provided with a vacuum connection tube which extends ¾ in. into the condenser-collection tube, thus permitting the removal of non-condensable gases during distillation.

The vapor-collection tube is shown in Fig. 3.54F2. The liquids distilled from the core sample are frozen on the walls of the bulb of the collecting tube. A bulb diameter of 1½-in. is required to contain these frozen liquids. The graduated portion of the condenser tube is calibrated in tenths of a cubic centimeter to a total liquid volume of 10 cc. A vacuum manifold permits the vacuum distillation of several samples simultaneously. Two standard vacuum pumps, a fractionating oil diffusion pump, and a precise vacuum gage comprise the auxiliary equipment.

3.542 Procedure

The core sample is placed in the core chamber of the vacuum distillation apparatus. The ground-glass joints are lightly covered with high-vacuum silicone grease, and the apparatus is assembled as shown in Fig. 3.54F1. A flask containing liquid nitrogen is elevated to submerge the calibrated condenser tube until the liquid-nitrogen level coincides with the base of the glass vacuum tube extending from the bottom of the core chamber. The liquid nitrogen is kept at this level throughout the operation. The system is evacuated with two standard vacuum pumps until the pressure is reduced to about 0.1 mm of mercury. The fractionating oil diffusion pump is then opened to the system, and the pressure is reduced to less than 0.01 mm of mercury. Heat is applied to the core chamber by the external heater, with the temperature being maintained at approximately 446 F. (230 C.) during the distillation.

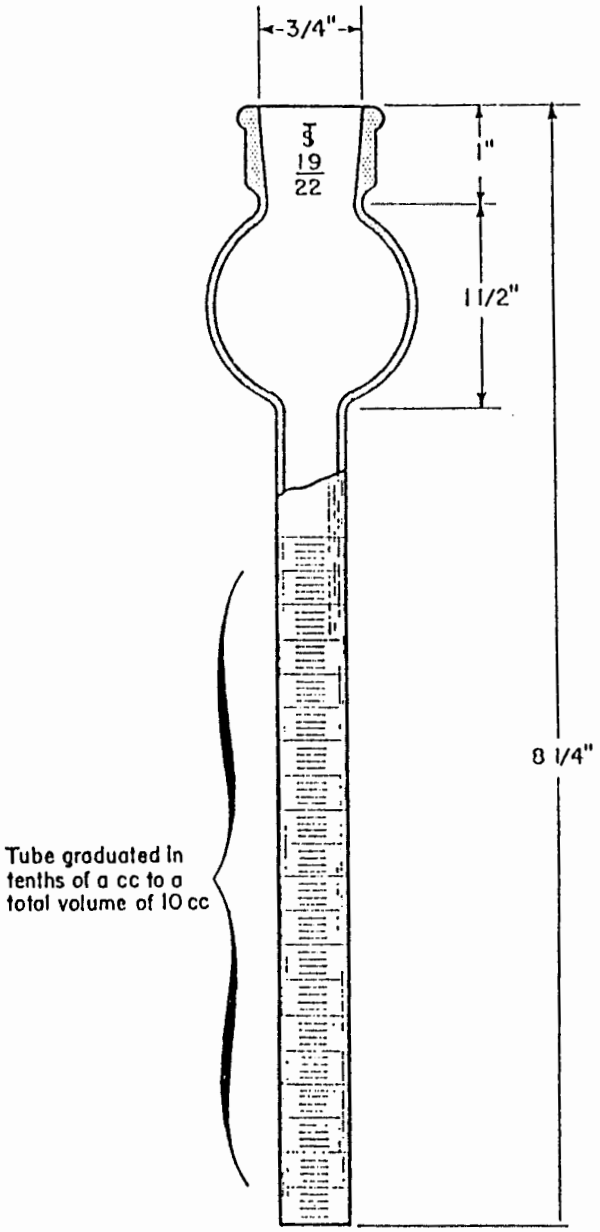


FIG. 3.54F2—PRODUCT CONDENSING AND RECEIVING TUBE

One hour after the core chamber reaches the operating temperature of 446 F. (230 C.) the vacuum is removed and the heat discontinued. The flask containing liquid nitrogen is lowered, the thermometer is removed, and the condenser tube is allowed to return to room temperature. When the liquids reach room temperature, the volumes of the liquids are recorded. If the water and oil are emulsified, it may be necessary to centrifuge the condenser tube to effect the separation of the liquids. It may be desirable to convert the volume of water distilled to the volume of the original salt solution. This is accomplished through the use of the following equation:

$$\text{Volume of original salt solution} = \text{volume of water distilled} \left(\frac{\text{density of distilled water}}{\text{density of original salt solution}} \right) \left(\frac{100}{100 - \text{percent salt by weight in original solution}} \right) \quad (2)$$

3.55 DISTILLATION EXTRACTION METHOD

3.551 Apparatus

General: The apparatus consists of a pyrex glass flask or a metal still, heated by suitable means and provided with a reflux condenser that discharges into a trap connected to the flask or still. The trap serves to collect and to measure the condensed water and to return the solvent to the flask or still. An extraction thimble, in which the core is placed, is supported in the flask or still.

Glass Flask: The glass flask (Fig. 3.55F1) has a flat bottom, wide mouth, and a long neck, with indentations spaced evenly around the base of the neck to support an extraction thimble containing the core sample.

Metal Still: The metal still is a vertical cylindrical vessel 2⅝ in. ID, 9⅛ in. long. The top plate contains an O-ring seal. The glass trap return to the still contains a 28/12 ball-and-socket joint with clamp. The extraction thimble is supported in the still by a wire holder.

Trap: The glass trap (Fig. 3.55F1) has a graduated section marked in 0.10-ml divisions. It has a capacity of 5 ml and the graduated section is approximately 130 mm long. The return to the flask has a drip tip. Larger or smaller traps may be required for some cores containing unusual volumes of water.

Condenser: The condenser (Fig. 3.55F1) is a water-cooled, reflux, glass-tube type, with a jacket approximately 300 mm long and the straight inner tube approximately 10 mm in diameter. The bottom of the condenser has a drip tip.

Extraction Thimbles:

a. Coarse round-bottom alundum thimbles, approximately 34 mm inside diameter and 80 mm long, are used to hold the core samples. The rate of drainage from the thimbles may be increased by cutting small slots in the bottom and placing a pad of glass wool or cotton in the bottom. A pad of glass wool or cotton is placed on top of the core sample to protect the sample from the drip of solvent from the trap return.

b. As an alternate, a paper extraction thimble approximately 33 mm inside diameter and 80 mm long may be used. These thimbles are used with a glass-covered bottle during weighing operations to minimize the change in weight of the thimble resulting from absorption of water from the air.

Extraction Cups: If it is desired, extraction cups with a siphon may be used to hold the thimble within the flask for alternate immersion and drainage during the extraction.

Drying Oven: Following extraction, the sample may be dried quickly in a vacuum (approximately 29 in.) oven (see 3.13).

3.552 Procedure

The thimbles containing the core sample are weighed quickly and placed in the extractors. The samples are weighed to the nearest 0.01 gram.

The samples are extracted with a solvent which is kept water-free because extraneous water will give erroneous results. When the atmosphere is nearly saturated with water vapor, care should be taken to prevent condensation of atmospheric moisture in the condenser and subsequent collection in the trap. Water hangup in condenser and trap may be an appreciable error if the core sample contains a small volume of water. The hangup of water may be removed by pouring a small volume of solvent containing a detergent down the condenser tube. However, when detergent is added to the solvent in the trap, it causes the meniscus between the water and solvent to become more nearly flat. The correction required by the change in the shape of the meniscus may be determined by adding a known amount of water to the trap, then adding solvent and detergent. For 5-ml traps this correction is about —0.03 ml.

Extraction is continued until no more oil or water may be removed from the sample (2 to 3 hours for crushed material, 6 to 8 hours for consolidated material). Samples containing low-gravity crude oils or very small pore channels require longer extraction time. Low-gravity, high-asphalt content crude oils are generally difficult to extract. Some oils of this type may not be completely removed after 24 hours extraction. To obtain complete removal of the oil, it may be necessary to use more than one solvent.

The rate of extraction may be increased by use of a glass extraction siphon cup fitted within the flask. The effect of alternate immersion and drainage may be obtained also by extraction in apparatus equipped with a water trap, as described, and then followed by additional extraction in a Soxhlet extractor after the water has been removed.

After complete extraction the thimble is removed, dried, and weighed. The loss in weight of the sample represents the combined weight of extracted oil and water from the sample. The weight of the volume of water measured in the trap is subtracted from the total liquid weight to determine the weight of oil extracted from the core sample.

To express the water and oil contents as percent of the pore space in the reservoir rock requires, in addition to the foregoing information, the porosity of the rock (3.3), the bulk volume of the sample (3.31), and the specific gravity of the oil produced from the reservoir.

3.553 Drying after Extraction

a. *Heating to Excessive Temperature:* If the sample is dried at temperatures above 200 F., water from the clay in the sample may be lost in the drying oven. This water is not free or mobile water in the reservoir at bottom-hole conditions. The loss in weight results in an error in the oil content of the core sample

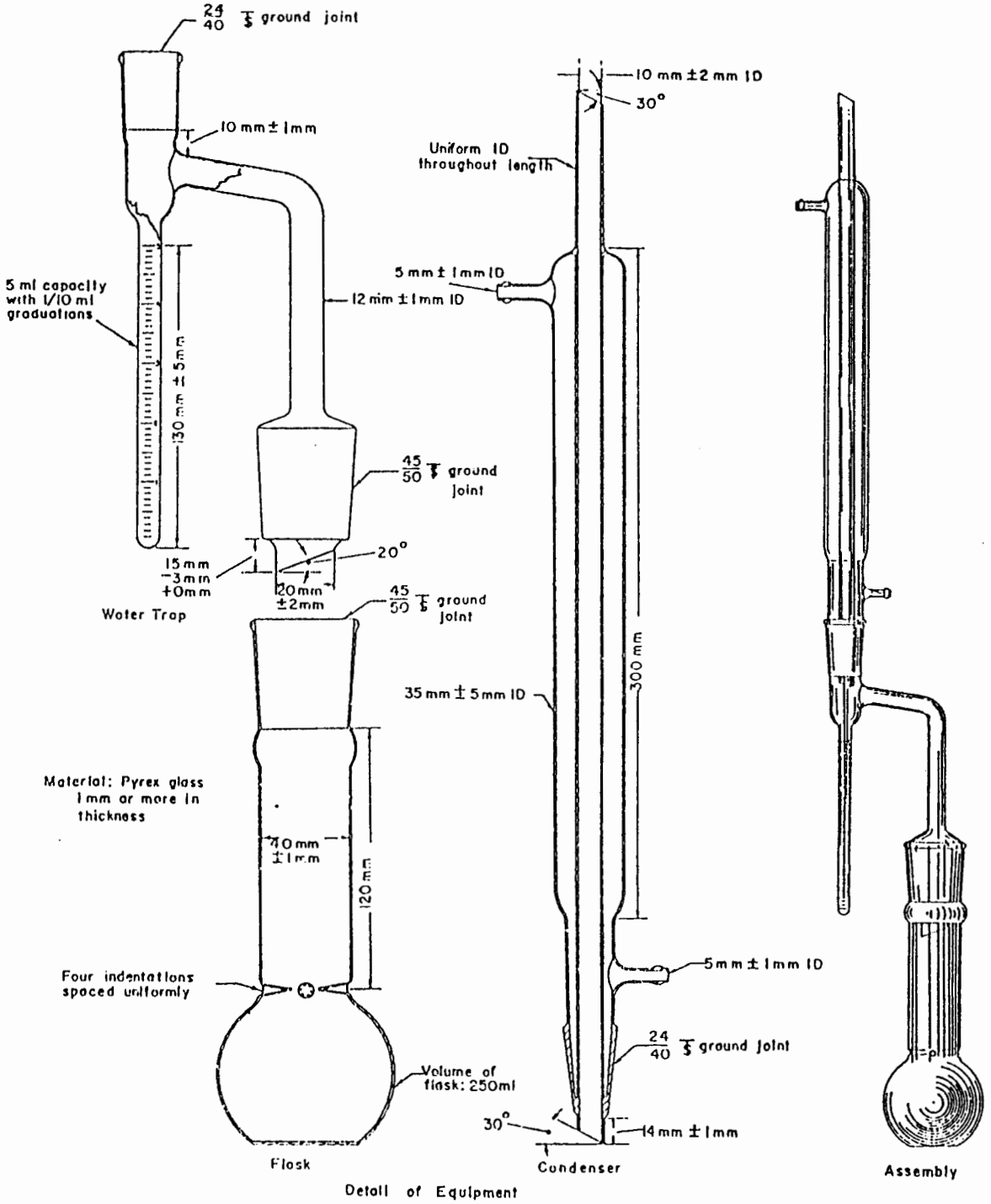


FIG. 3.55F1—APPARATUS FOR SIMULTANEOUS DETERMINATION OF OIL AND WATER SATURATIONS OF OIL SANDS

This error can be minimized by drying at temperatures below 200 F. in a vacuum oven.

b. *Incomplete Drying:* If the core sample is not completely dry after extraction, the calculated oil content will be less than the true value. To prevent this error, it is suggested that the samples be dried in a vacuum oven over night when time permits.

3.56 BULK VOLUME BY MERCURY DISPLACEMENT

3.561 Apparatus

a. Steel or glass pycnometer.
b. Container to hold displaced mercury.
c. Balance with accuracy of 0.01 gram.
d. Weighing dish.

3.562 Procedure

The pycnometer is filled with clean mercury and the top is inserted. Excess mercury will be forced through the air hole in the top. The excess mercury is brushed from the top and sides of the pycnometer with a camel's-hair brush. After placing the pycnometer in a suitable container, remove the top, measure the temperature of the mercury, and immerse the sample in the mercury by replacing the top. *(Note:* The inside of the top should be equipped with prongs to force the sample into the liquid. It should also be coned to facilitate removal of trapped air[8]). The sample should not touch the sides of the pycnometer. After the top is seated, brush off any mercury adhering to the outside of top or sides. The mercury displaced by the sample is transferred to the weighing dish and its weight is determined. The bulk volume of the sample is obtained by dividing the weight of mercury displaced by the density of mercury. The density of mercury at the temperature of displacement can be found in chemical or physical handbooks.

Instead of weighing, a direct measure of the bulk volume can be made. The displaced mercury is transferred to a burette or accurately calibrated tube to measure the volume of mercury. This volume is the bulk volume of the sample.

3.57 BULK-VOLUME METER

3.571 Apparatus

Bulk-volume Meter: This instrument measures bulk volume by displacing a suitable liquid into an inclined graduated glass tube by submerging the core sample under mercury in an adjacent connected vessel. The apparatus is shown in Fig. 3.57F1.

3.572 Procedure

The bulk-volume meter is calibrated by submerging a steel blank in the mercury chamber. The mercury volume in the cylinder is adjusted until the oil column reads exactly a definite point on a suitable scale mounted behind the oil column. The meter is previously calibrated with a series of blanks of known volume over the range of interest and a curve drawn for volume vs. scale readings. If room temperature is constant, practically no variation in calibration will be noted after the first 2 or 3 samples have been measured.

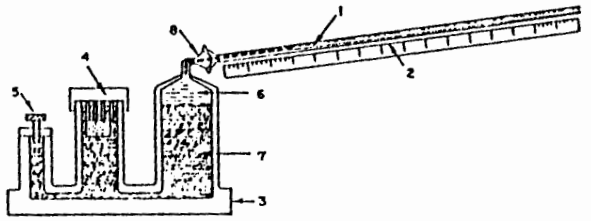
A sample of the core to be examined is submerged in the mercury cylinder and the resultant liquid level is read on the scale. The value read on the scale is converted to volume through use of the calibration curve. The values may be taken from the curve and used in chart form for convenience.

The meter is calibrated every 6 to 10 samples. More frequent calibration is necessary when measuring either friable sandstones (mercury becomes dirty and volume increases), or vugular limestones (vugs trap mercury as sample is removed and mercury volume decreases).

3.58 PORE VOLUME FROM GRAIN DENSITY BY DRY METHOD

3.581 Apparatus

a. Pulverizer with adjustable tolerance between the grinding plates.



1—Precision tubing—bore approximately 3 mm ID.
2—Calibrated scale, reading in cubic centimeters
3—Steel vessel
4—Cap with sample holddown prongs
5—Mercury volume adjustment
6—Oil
7—Mercury
8—Ground joint connection

FIG. 3.57F1—BULK-VOLUME METER

b. U. S. Bureau of Standards, sieves, 60-mesh and 100-mesh.

c. Analytical balance, with accuracy to ±0.1 milligram.

d. Modified Boyle's Law porosimeter.

The porosimeter construction is simple (Fig. 3.58F1), consisting of a board-mounted mercury column with leveling bulb, a 20-ml pipette, an oil manometer, an aluminum cup sample holder, and a connecting mercury-displacement pump with a calibrated milliliter mercury scale having a capacity of approximately 100 ml of mercury.

The column of mercury, pipette, manometer, sample holder, and pump are all connected in sequence with ¼-in. copper and plastic tubing so that pressure exerted into the sample cup from the mercury column registers on the oil manometer and can be counterbalanced by pressure from the mercury-displacement pump. No special materials are necessary. Standard laboratory glassware is satisfactory.

3.582 Procedure

An extracted, dried sample is pulverized and then sieved through a 60-mesh sieve onto a 100-mesh sieve. A 150- to 200-gram portion of the sample remaining on the 100-mesh sieve is placed into a tared 400-ml Griffin beaker and weighed. The weight of the sample is recorded to four decimal places.

Before introduction of the sample, the porosimeter is calibrated to a solid standard of known bulk volume. For the equipment listed, solids having bulk volumes of 40-ml and 50-ml displacement of mercury are used. Either solid is placed into the cup and the cup screwed into place on the apparatus.

With the cup in place, the leveling bulb on the mercury column is raised and/or lowered to fill the 20-ml pipette to a marked-level reference point. This

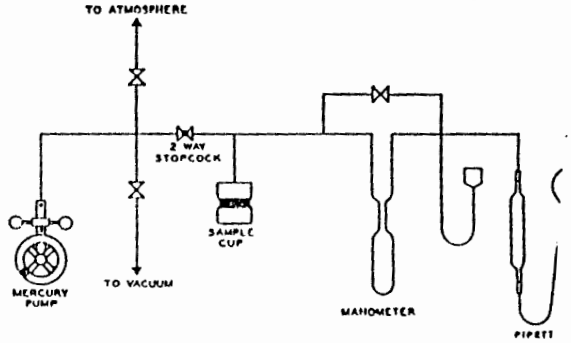


FIG. 3.58F1—SCHEMATIC DIAGRAM OF GRAIN-DENSITY APPARATUS

reference point is permanently etched into the glass of the pipette. The pressure thus exerted into the cup is registered by the oil manometer. The displacement pump, which previously has been brought to rest at zero, is now caused—by slow hand pressure—to counterbalance the mercury column pressure. This is accomplished when the two levels in the oil manometer are equal. Under this condition the milliliters of mercury required are recorded from the calibrated scale of the pump.

This procedure is repeated from beginning to end until at least two final readings on the pump scale are in agreement.

These several readings, as recorded, are averaged; and their mean value is used as the final reading.

The other solid of known bulk volume is also subjected to this procedure.

Once the solid standards have been run, the core sample to be tested is also subjected to this procedure.

There are now three values, viz.:

a. Total volume of empty sample cup.
b. Displacement constant for 1 ml of mercury from pump.
c. Displacement in the cup by the sample.

After several sample runs, it is advisable to recheck the standard solid values. This is necessary because of possible change in the temperature of the instrument which would cause mercury expansion.

3.583 Calculations

The displacement in the cup caused by 1 ml of mercury from the pump is a necessary constant to be applied in calculating the total volume of the empty cup and in calculating total displacement when the cup is occupied by a sample:

$$M = (V50 - V40) / (R40 - R50) \qquad (3)$$

Wherein:

M = displacement constant.
V50 = bulk volume of solid (50 ml of mercury displacement in bulk-volume meter).
V40 = bulk volume of solid (40 ml of mercury displacement in bulk-volume meter).
R50 = average of readings obtained from displacement pump, in milliliters, when solid is in sample cup and pressure from mercury column has been counterbalanced by pump.
R40 = average of readings obtained from displacement pump, in milliliters, when solid is in sample cup and pressure from mercury column has been counterbalanced by pump.

Then the total volume of the empty cup is calculated:

$$b = M(R50) + V50 \qquad (4)$$

Wherein:

b = total volume of empty cup expressed in milliliters.
M = displacement constant for 1 ml mercury from pump [equation (3)].
R50 = see equation (3).
V50 = see equation (3).

By substituting *R40* and *V40* values in equation (4), the *b's* should equal.

After *M* and *b* are determined, then the grain volume of the sandstone sample is calculated:

$$\text{Grain volume} = b - RM \qquad (5)$$

Wherein:

b = see equation (4).
M = see equation (4).
R = averages of readings obtained from displacement pump with sandstone sample in sample cup.

The grain density is then calculated:

$$\text{Grain density} = \text{weight of sample/grain volume} \qquad (6)$$

Consequently, the percent total porosity is calculated:

$$\text{Total porosity percent} = \text{bulk volume} - \frac{\text{(weight of extracted, dried saturated sample/grain density)}}{\text{bulk volume}} \qquad (7)$$

3.59 PORE VOLUME FROM GRAIN DENSITY BY WET METHOD

3.591 Apparatus

a. Mortar and pestle.
b. 100-mesh sieve.
c. 50-cc calibrated volumetric flask and stopper.
d. Constant-temperature water bath.
e. Analytical balance.

3.592 Preparation

Weigh a dry, clean 50-cc volumetric flask and its stopper. Transfer approximately 50 cc of a liquid of known density—e.g., toluene, water, etc.—into the flask. Insert the flask with the liquid into a constant-temperature water bath. Allow the temperature of the liquid to reach equilibrium with its surroundings. To the flask add liquid with an eye dropper until the bottom of the liquid meniscus reaches the 50-cc reference mark.

Remove the flask from the bath and allow to cool. Stopper the flask and weigh the stoppered flask with its contents.

Subtract the weight of the empty stoppered volumetric flask and this result should be the weight of 50 cc of liquid. Record the flask number and the weights for future use.

Crush about 30 grams of the sample in a mortar and sift the powdered sample through a 100-mesh sieve. Continue crushing the coarser particles until grain has been obtained. Transfer the powder and the coarser particles to a petri dish and dry in the oven.

NOTE: Usually a grain density determination is carried out on each successive core sample of the formation if there is a change in the lithology. For a fomation interval of no lithological change, it is recommended that a grain-density determination be carried out on every third successive core sample of the interval.

3.593 Procedure

Using a funnel, transfer about 15 grams of the dried, crushed core sample into a 50-cc calibrated volumetric flask. Weigh the sample in the stoppered flask. The flask containing the sample is weighed to 0.001 gram. The flask and sample are then evacuated for about 20 min. The rate of evacuation at first must be controlled, so that the powdered sample is not

drawn into the upper parts of the flask and into the vacuum system. After evacuation, add some liquid to the flask. Whirl the flask and its contents in order to completely wet the powdered sample with the liquid.

NOTE: If water is used as the liquid, a wetting agent should be added to insure complete wetting of the powdered sample.

Add more liquid, almost to the 50-cc reference mark. Insert the flask and its contents into a constant-temperature water bath until the temperature of the liquid in the flask becomes constant. With an eye dropper, add liquid to the flask until the bottom of the meniscus reaches the reference mark. Remove the flask from the water bath and allow to cool. Weigh the stoppered volumetric flask with its contents.

The weight of a 50-cc volumetric flask containing 50 cc of liquid has already been determined in 3.592.

The portion of crushed core sample placed in this flask displaced an equivalent volume of liquid. By determining the density of the liquid and the weight of the displaced liquid, it is possible to calculate the displaced volume of liquid. The weight of the sample has been measured and with the relationship, *grain density = weight of sample volume of sample*, the grain density of the core sample is calculated.

The grain-density value found by experiment is assumed to apply to the whole extraction sample. The grain volume of the extraction sample is given by the quotient of sample weight divided by grain density, and the pore volume is the difference between the bulk volume and grain volume. The total porosity is the quotient of pore volume divided by bulk volume.

3.5.10 BOYLE'S LAW SINGLE-CELL METHOD

3.5.10.1 Apparatus

The Kobe instrument is one example of a Boyle's Law single-cell unit. (Fig. 3.5.10F1). The major piece

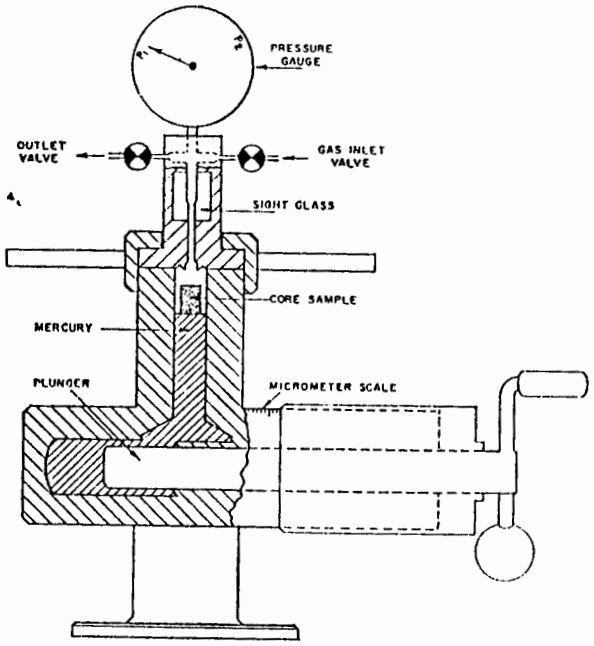


FIG. 3.5.10F1—SCHEMATIC DIAGRAM OF KOBE POROSIMETER

of apparatus is a piston-type, crank-operated, mercury pump, mounted horizontally. The pump plunger is attached to a precision screw and a micrometer scale. This assembly can be rotated as a unit by a crank. In this way the mercury level in the core chamber can be regulated, and the volume of gas confined can be changed by the operator. Each complete turn of the crank changes the volume of the core chamber 1 cc. The micrometer scale, graduated in 100 divisions, measures differential volumes within the core chamber to 0.01 cc.

The cylindrical core chamber is mounted vertically on top of the pump. Cores may be introduced into the core chamber through the top, and float on the mercury inside. A removable threaded cap seals the core chamber. A sight glass with a reference line is situated at the top of the cap. This glass is a part of the core chamber and is concentric to it. Above the sight glass, there are two openings to the core chamber—the first, the inlet valve to admit gas (usually air or helium); and the second, the outlet valve which is a vent to the atmosphere.

A precision pressure gage is attached at the top of the closure assembly to register pressure within the core chamber. Only two pressures need be indicated by this gage: *a*, Atmospheric pressure, or P_1; and *b*, an elevated pressure, P_2. The latter pressure level, P_2, is on the order of three to four atmospheres absolute. The gage used must be capable of indicating these two pressure levels precisely. The earlier instruments used a dead-weight gage. Some of the later models use a Bourdon-type gage. On some instruments, the gage is mounted to one side of the porosimeter and connected to the top of the core chamber by a small-bore metal tube in order to reduce the weight of the cap assembly. There should be some degree of flexibility in the tube to enable the operator to open and close the core chamber. Instruments equipped with a dead-weight gage should have a means of ascertaining whether the gage piston has been raised to a reference level. This can be done easily by projecting a magnified image of an indicator (attached to the gage) onto a screen with a reference line drawn across it.

Even though a number of refinements have been made by some users, the basic principles and operating procedures remain about the same. The following procedure is a description of the operation of the Kobe unit.

3.5.10.2 Procedure

a. Close and seal core chamber.

b. Be sure gas inlet valve is closed.

c. Outlet valve should be open.

d. By means of the pump, raise the mercury level in the core chamber to the reference line on the sight glass. The stroke described is a *displacement* stroke. To minimize errors from backlash, the pump should be advanced in approaching a reference point or compression reading. Under these conditions, the operator would be turning the crank clockwise on approaching a point where a reading is to be made.

e. Note and record the micrometer reading at this point. This reading will be called R_1.

f. Open the gas inlet valve. Gas should be admitted to the core chamber so that only a small amount bleeds from the outlet valve (wide open) during step g.

g. Retract the pump to about 2 cc beyond the starting point. Use of only one starting point is advised wherever possible. Some users find the 50-cc level usable for most cores. Larger samples may require that the 75-cc starting point be used.

h. Close gas inlet valve.

i. Advance pump plunger to starting point.

j. After pausing momentarily, close the outlet valve. At this point, the gas confined in the core chamber is at P_1, or atmospheric pressure. Volume of gas in the chamber at this point is V_1 at P_1.

k. Advance the pump plunger until gas in the core chamber is compressed to P_2.

l. Read the value indicated on the micrometer scale. This reading is R_2 and the pressure is P_2. Volume of gas is V_2.

One displacement and one compression stroke have been described. Since no sample was in the core chamber, this pair of readings is called a "blank run" or "blank."

m. Open the outlet valve slowly to bring the pressure in the core chamber to atmospheric (P_1). On models using the dead-weight gage indicator, the pump plunger should be retracted a few turns to lower the piston in the gage to the point of rest, prior to opening the outlet valve. This is to prevent the gage from dropping back sharply upon releasing the pressure.

n. After the blank run has been completed, open the core chamber and insert a sample.

o. With the sample in the core chamber, follow the procedure outlined in steps a. through m.

p. The micrometer value for the displacement reading will be termed R_3.

q. The value for the compression reading will be called R_4, and the pressure will again be P_2. The volume of gas at P_2 will be V_4 (at the start of the compression stroke, it was V_3 pressure P_1).

r. Remove core. Leave instrument with gas inlet valve closed, outlet valve open.

3.5.10.3 Determination of Compression Factor C_f

a. Make a "blank run" (in this case, displacement reading is not needed) using the customary starting point L_0. The compression reading so obtained is C_0.

b. Complete a second blank run in a similar manner as step a., *EXCEPT* use a lower starting point, L_0—*10*. For example, if 50 is the usual starting point, it is suggested that the blank run in step a. should start at 50 and in step b. at 40. This will give the effect of placing a 10-cc non-porous solid in the core chamber of the porosimeter.

c. The compression factor can be computed from the formula:

$$C_f = 10/[10 - (C_0 - C_1)] \qquad (8)$$

d. It should be emphasized that appreciable barometric pressure changes affect the compression factor considerably and that, in localities where significant changes occur, this factor should be computed and charts made to cover the ambient barometric range. The compression factor can also be expressed by the relationship:

$$C_f = P_2/(P_2 - P_1) \qquad (9)$$

Wherein: P_2 is the floating pressure, and P_1 is barometric pressure.

e. The micrometer scale calibrations can be checked by adding a weighed amount of mercury to the instrument and noting the resulting shift in the displacement readings.

3.5.10.4 Calculations

The four readings which have been made are:

	Displacement Stroke	Compression Stroke (P_1 to P_2)	Volume Reduction At P_1	Volume Reduction At P_2
Blank run	R_1	R_2	V_1 to	V_2
Sample run	R_3	R_4	V_3 to	V_4

From these data bulk volume, grain volume, and pore volume can be calculated in the following manner:

a. Bulk volume $= R_3 - R_1$.

b. Grain volume $= C_f\ (R_4 - R_2)$. C_f = compression factor.

c. Pore volume = (bulk volume — grain volume)
$= (R_3 - R_1) - C_f(R_4 - R_2)$.

Operators have noted that the first one or two sample runs in this type of porosimeter are erratic. This is caused by the Joule-Thompson effect. For best results, prior to running a group of samples the operator should make two or three blank compression runs. It is recommended that the instrument be operated at the rate of about 20 to 30 samples per hour.

The gas inlet should be connected to a supply of dry gas to prevent condensation of water during the compression strokes. If air is used, it should pass through an adequate drying tube prior to entering the inlet valve. The use of helium has produced the most satisfactory results, since it is adsorbed on surfaces only very slightly whereas the dimolecular gases such as nitrogen and oxygen are very noticeably adsorbed. When using helium, it is superfluous to evacuate the core in the core chamber to remove air prior to beginning a compression stroke. If helium is used, and the sample chamber is flushed with helium but not evacuated, virtually all the air remaining within the core chamber is within the pore channels of the sample. During the compression stroke, the partial pressure of the air inside of the core, and hence the degree of adsorption, remains unchanged.

3.5.10.5 Precautions

The sensitivity of this type porosimeter during compression strokes can be impaired if the gas volume around and above the core is excessively large in comparison to the core volume being measured. For this reason, it is imperative to make all gas passages above the core chamber to the gage and the valves as small and as short as practical. In this regard, it is also advantageous to begin a compression run at the lowest practical starting point. Cores should still float on top of the mercury at the end of each compression stroke. If cores are deeply immersed in mercury during this operation, passages to some pores are obstructed to the flow of gas, and in some cases the core can even be caused to imbibe mercury.

3.5.11 BOYLE'S LAW—DOUBLE-CELL METHOD

3.5.11.1 Procedure

Basically, the instrument consists of two connected chambers with a means of measuring the pressure in each chamber. Following a bulk-volume measurement, the core sample is placed in one chamber and the gas pressure in this chamber is adjusted to some known value. The gas in the second chamber is adjusted to some different known pressure. The pressure is equalized and measured and the final volume is known.

From these data and Boyle's Law, the grain volume is calculated.

Three distinct modifications of the procedure are in general use, as discussed following.

Modification A[9]

In this modification, the pressure in the core chamber is initially atmospheric, while that in the second chamber is some fixed higher value in the range of 40-100 psig. The pressure is equalized between the chambers and measured. To simplify calculations and to compensate for slight deviations from Boyle's Law, the instrument is calibrated with known volumes in the core chamber, and the relationship between grain volume and the final pressure is developed empirically. Sample grain volumes are then read from the prepared table of volumes vs. pressure readings.

Modification B

This modification is similar to modification A, except that the pressure in the core chamber is initially a fixed high value (about 10 psig) while the other chamber is at atmospheric pressure. The apparatus is shown in Fig. 3.5.11F1.

Let: V_x = grain volume, in cc.
V_o = volume of cell, in cc.
P_o = high-pressure manometer reading, in cm.
P_a = atmospheric pressure, in cm Hg.
V_L = volume of lines from cell valve to mercury surface of reading manometer, in cc.
C = cross-sectional area of reading manometer, in sq cm.
R = reading of manometer, in cm.
K = instrument constant zero pressure reading.

Then: $V_x = V_o - [V_L + C\,(P_o + K - R)]\,/(P_o/K - R) - 1$ (10)

assuming that the ideal gas law applies for helium at the pressures used.

Modification C[10]

As in modification B, the core chamber is initially at high pressure, but the gas is then expanded into a gas burette where the volume at atmospheric pressure is measured.

Let: V_B = volume of the bomb.
V_g = volume of gas in the burette.
P_B = absolute pressure of gas in the bomb.
P_g = absolute pressure of the gas in the burette (also the pressure of the gas in the bomb after expansion of gas).
y = the factor to compensate for the deviation of a gas from the ideal gas law at pressure P_B.
V_x = grain volume.
$V_B = V_g/[(yP_B/P_g) - 1]$

NOTE: Equation (6) of ref. 10 is in error. This formula is likewise applicable in determining the void space in the bomb with the specimen in it (V_Y).

Then: $V_x = V_B - V_Y$ (11)

Effective porosity is then reported as percent of bulk volume.

The greatest sensitivity is obtained from the porosimeter when the core sample is as large a portion of the core-chamber volume as is possible. Most users of the Boyle's Law type porosimeters have found it advisable to set up a definite time cycle in the operation of the instrument. The same timing is followed both in calibration and in porosity determinations. In this way, the changes in the temperature of the gas

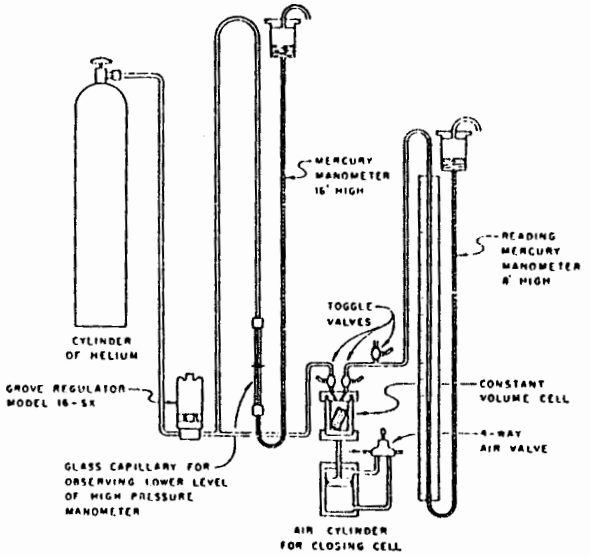


FIG. 3.5.11F1—BOYLE'S LAW DOUBLE-CELL POROSIMETER

caused by expansion and compression are accounted for in the calibration. The accuracy for small cores can be increased by using a smaller core chamber or by partially filling the chamber with solids of known volume.

3.5.12 WASHBURN-BUNTING METHOD[6]

3.5.12.1 Procedure

The rock specimen is placed in a sample chamber as shown in Fig. 3.5.12F1, and the following steps are performed.

a. Make a blank determination with a piece of glass of approximately the same shape and size as the core sample to be tested. This gives a zero reading which corresponds to adsorbed air on the surface of the test piece.

b. Place the core sample in the sample chamber above the mercury and leave the upper stopcock open.

c. Raise the leveling bulb until the mercury reaches above the stopcock. This must be done slowly and carefully in order to avoid the jetting of mercury through the upper stopcock.

d. Close the stopcock.

e. Lower the leveling bulb until the core floats in the barometric vacuum on top of the mercury. Let the core stand in this position for a few minutes in order to allow the complete escape of air from the core.

f. Lift the leveling bulb slowly until the two levels in the two branches are at the same height. This assures the restoration of atmospheric pressure on the air which escaped from the core. Steps e. and f. should be repeated a minimum of 3 times. Since the apparatus as well as the core is presumably at room temperature, the air volume in the graduated capillary represents the true effective pore volume of the core. The effective porosity in percent is given by:

$\phi = 100\ [(\text{Volume from step f.—zero reading from step a.})/\text{bulk volume}]$ (12)

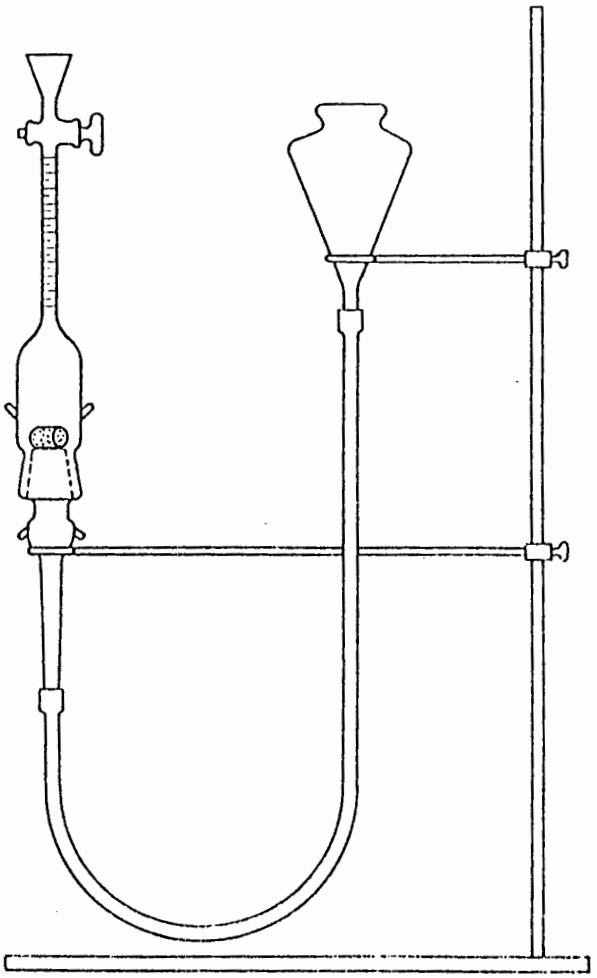


FIG. 3.5.12F1 — WASHBURN-BUNTING TYPE POROSIMETER

3.5.13 HYDROCARBON RESATURATION METHOD

3.5.13.1 Apparatus

a. An analytical balance accurate to 1 milligram, preferably one on which rapid weight determinations can be made.

b. A suitable vacuum source capable of maintaining 0.01 mm of mercury pressure.

c. Suitable containers which can be used to hold cores and deaerated liquid under vacuum.

d. A filtered low-viscosity, low-vapor-pressure liquid of known density for the purpose of saturating the core samples. (Some liquids which have been used are kerosene, white oil, toluene, and decane.)

3.5.13.2 Procedure

a. Obtain the weight of the dry, clean sample. (The sample should be desiccated over a suitable dehydrating material, such as $CaCl_2$, prior to the determination of the dry weight. The desiccating period should be long enough to eliminate water vapor from the dry sample.)

b. Place the weighed, dry sample in a chamber (vacuum flash or dessicator) and apply a high vacuum for about 8 hours. For very low-permeability samples, the evacuation period should be as long as 12 to 18 hours (overnight).

c. At the end of the evacuation period, a deaerated liquid is drawn slowly into the evacuated vessel containing the core sample. The core is allowed to saturate by capillary action. After the sample has been completely submerged in the liquid, the vacuum is continued for an additional 30 min to 1 hour, or until all evidence of bubbling has ceased.

d. The evacuated chamber containing the core completely submerged is then opened to the atmosphere for at least 1 hour; then the vacuum is applied again for a period of at least 1 hour. This is necessary to assure as complete saturation of the sample as possible. After the vessel has again been opened to the atmosphere for 30 min to 1 hour, the sample is ready to be weighed. (Some laboratories prefer to soak the samples for 24 hours under a good vacuum and others include a step pressuring the liquid surrounding the sample to as high as 3,000 psi to assure complete saturation.)

e. The sample is removed from the saturating vessel and weighed submerged in the saturating liquid, utilizing a suitable arrangement on the analytical balance which will allow the sample to be suspended freely in the liquid. (The tare weight of the suspended device must be determined prior to weighing the sample.)

To facilitate weighing the samples, an automatic balance may be altered by removing the pan and replacing it by a counterweight and sample cradle such that the cradle, when suspended in the liquid, will have an apparent weight of zero. Care should be taken that, at the surface of the liquid, only the fine suspending wire passes from the air into the liquid. An error would occur if a portion of the cradle or the sample disturbed the surface of the liquid.

The saturated samples are placed in a tray of sufficient depth for complete submersion of the samples and cradle in the liquid and sufficient breadth to allow manipulation of the samples by tongs while the tray is within the balance. If transfer of samples through air is necessary, it should be done rapidly to prevent evaporation from the pores. By using a smaller container for saturation in the vacuum desiccator and placing this into the larger tray of liquid, a transfer in air is unnecessary.

Each sample is individually weighed on the cradle while suspended under the liquid. As each weighing is completed, the weighed sample should be returned to another position in the tray, and not removed from the tray. This is important since the level of the liquid must be kept constant in order to obtain good accuracy. After weighing each batch of samples, density of the liquid is determined. This must be done with accuracy, since on permeable samples at least, the liquid density is probably the greatest source of error. A good-quality pycnometer should be used. Weighings should be performed rapidly and the liquid density taken immediately so that temperature corrections are minimized. Temperature of the liquid should not vary by more than 1 deg F. during the measurements on one group of samples.

f. The saturated weight of the sample is determined after carefully hand-blotting the excess surface liquid from the sample. Blotting materials such as cloth or paper may desaturate the sample. Therefore, hand wiping is preferred. (If the pore volume of the sample is already known from another measurement, this step may be omitted.)

3.5.13.3 Precaution

Error can be introduced into this procedure for the determination of pore volume and bulk volume by: *a*, not attaining 100-percent liquid saturation of the core sample during the evacuation procedure; and *b*, improper surface wiping of the sample prior to the determination of the saturated weight.

3.5.13.4 Calculations

The procedure for the calculation of effective porosity is outlined following.

a. Net submerged weight = submerged weight — tare weight of the device used to suspend the sample in the liquid media.
b. Weight of liquid in the sample = saturated weight—dry weight.
c. Pore volume = weight of liquid in the sample ÷ liquid density.
d. Bulk-volume buoyancy = saturated weight — net submerged weight.
e. Bulk volume = bulk-volume buoyancy ÷ liquid density.
f. Grain-volume buoyancy = dry weight — net submerged weight.
g. Grain volume = grain-volume buoyancy ÷ liquid density.
h. Pore volume = bulk volume — grain volume. (Any difference between this pore volume and the pore volume in c. indicates an arithmetic error.)
i. Effective porosity = pore volume ÷ bulk volume.
j. Grain density = dry weight ÷ grain volume.

3.5.14 MERCURY-PUMP METHOD
(U. S. Patent No. 2,874,565)

3.5.14.1 Apparatus

The mercury pump, Fig. 3.5.14F1, is a high-pressure volumetric displacement pump to which a high-pressure stainless-steel sample chamber is attached. The displacement is accomplished by a screw-actuated plunger which operates through a packing gland into a cylinder. The plunger and a micrometer scale attached to its actuating screw are precisely machined, allowing the displacement of the plunger to be read very accurately, the micrometer scale being graduated in units of 0.01 cc. A linear scale past which the plunger moves is graduated in cubic centimeters. The sample chamber, which will hold samples up to approximately 25 cc, is closed by a cap equipped with a needle valve which allows the chamber to be purged of air. The cap seats against an O-ring and is locked in place by a quick-action yoke-and-screw device. The cap is fitted with small stainless-steel pins to prevent the sample touching the top or sides of the chamber. A vacuum gage is connected to the cylinder to indicate the pressure of the system. A high-pressure valve is placed between the cylinder and the vacuum gage to protect the vacuum gage when the system is under pressure. The mercury in the system is continuous from the cylinder to the gages and into the bottom of the sample chamber, so that when a sample is in the chamber and the chamber is filled with mercury, there is no gas in the entire system except that which may be in the pore space of the sample or purposely introduced for calibration purposes.

3.5.14.2 Procedure

The bulk volume of a cleaned and dried core sample of 10 to 20 cc in volume, either shaped or irregular, is obtained by mercury displacement. The pressure in the vessel containing the sample and the confirming mercury is reduced to approximately half an atmosphere. The volume of the expanded air or gas from the core space is measured accurately. The pore volume is calculated using Boyle's Law. The percent porosity is obtained from the pore volume and bulk volume measurements. The procedural details follow.

a. Place cap on sample chamber, lock it in place and open the needle valve.

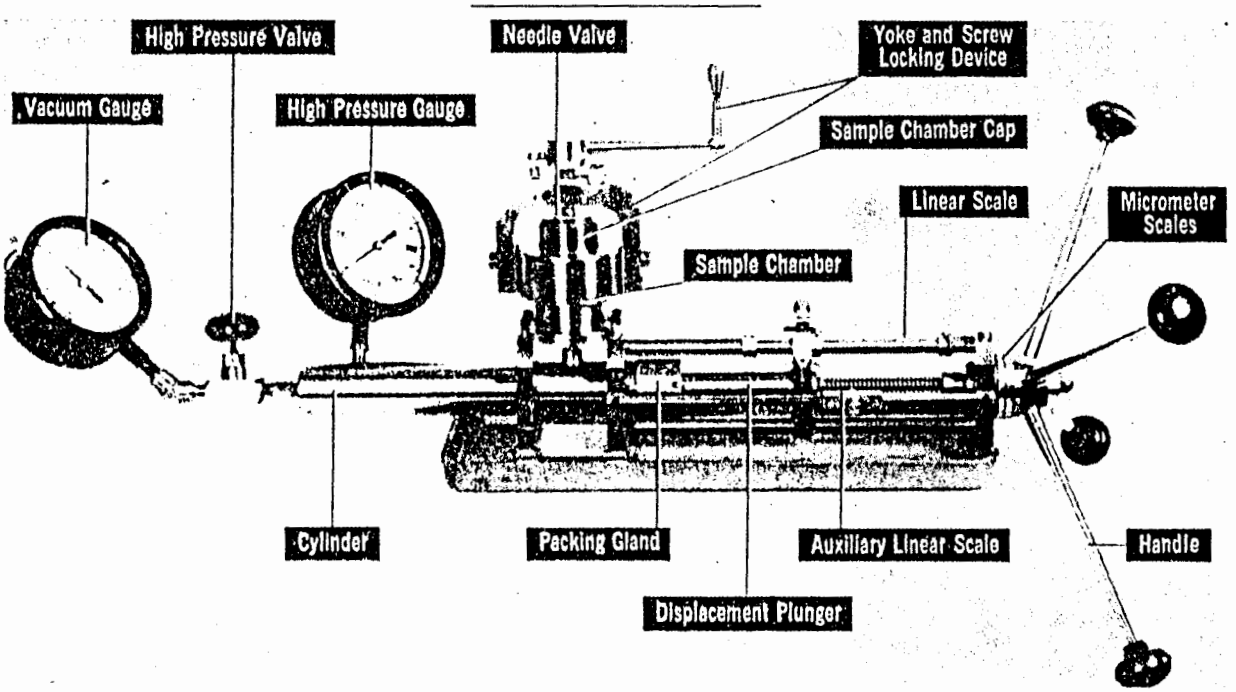


FIG. 3.5.14F1—MERCURY PUMP

b. Open the high-pressure valve to the vacuum gage three quarters of a turn.

c. Displace the pump plunger so as to advance the plunger into the cylinder until the sample chamber is completely filled with mercury, i.e., until a small drop of mercury appears in the recess below the needle valve. The amount of mercury in the recess should be such that no mercury shows above the needle valve when it is closed, and no air should be trapped below the needle valve when it is closed.

d. Set the vacuum-gage pointer to zero.

e. Set the pump scales to zero.

f. Close the needle valve firmly, so it will not leak subsequently when vacuum is applied.

g. Withdraw the pump plunger until the vacuum gage reads 16 in., tapping the gage during this time to insure free movement of the pointer.*

h. Record the micrometer scale reading and label it *C*.

i. Open the needle valve and withdraw the plunger to between 5 and 6 cc. Return the pump to exactly 5.00 (use both linear and micrometer scales).*

j. Close the needle valve.

k. Withdraw the plunger until the vacuum gage reads 16 in., tapping the gage as before.*

l. Record the linear-scale and the micrometer-scale readings as one reading and label it *R*.

m. Open the needle valve and advance the plunger into the cylinder until the scales read 5.00, as in step i.

n. Repeat steps j. through m. until five *R* values have been recorded. Obtain an average of five *R* values.

o. Calculate a factor, *f*, using the following formula:

$$f = 5.00 \,/\, [R\ (avg.) - C - 5.00] \qquad (13)$$

p. Open the needle valve and repeat step c. to rezero the pump.

q. Withdraw the plunger approximately 30 cc.

r. Open the sample chamber and insert a sample that has been extracted and dried. Replace and lock the cap.

s. Advance the plunger into the cylinder carefully until a drop of mercury appears in the recess below the needle valve as in step c.

t. Record the linear-scale and micrometer-scale readings as one reading. This is the bulk volume of the sample in cubic centimeters.

u. Set the linear scale to zero and the micrometer scale to the value of *C* found in step h.

v. Close the needle valve.

w. Withdraw the plunger until the vacuum gage reads 16 in. as in step g.

x. Record the linear-scale and micrometer-scale readings as one reading. This is the apparent pore volume of the sample.

y. Multiply the apparent pore volume found in step x. by the factor, *f*, found in step o. The product is the true pore volume.

z. Divide the true pore volume found in step y. by the bulk volume found in step t. and multiply the quotient by 100 to obtain the percentage by volume of pore space.

*To minimize errors caused by backlash, all pump readings should be taken as the plunger is being advanced into the cylinder, except for the vacuum readings. The vacuum readings should be taken as the plunger is withdrawn fr the cylinder.

A study of the foregoing procedure will show that the gas (air) in the pore space of a sample is expanded to approximately twice its original volume because the pressure of the system is reduced to approximately half of the barometric pressure. Since there is no air in the system other than that which may be in the sample pores, it follows that the amount of displacement of the pump plunger necessary to reduce the pressure to 16 in. of vacuum is an approximate measure of the pore volume. The calibration factor *f* converts the approximate, or apparent, pore volume to the correct pore volume.

In practice, it is impractical for several reasons to use exactly half of the barometric pressure as a reference vacuum pressure. Therefore, a vacuum reference of 16 in. is used, regardless of the barometric pressure, and the instrument is calibrated to measure pore volume empirically. The calibration factor compensates for the pressure ratio, the single-arm manometer effect of the vacuum gage, and the head of mercury on the sample after the expansion has been effected. The pump correction found in step h. corrects for vacuum gage displacement and small amounts of air that may be trapped in the system.

Steps c. through o. constitute the calibration procedure and need not be repeated for each sample. A calibration should be made when starting a set of samples, and occasionally thereafter.

3.5.15 AIR PERMEABILITY DETERMINATION

3.5.15.1 Procedure and Calculations

The dimensions of the core sample must be obtained to calculate its permeability. The length and cross-sectional dimensions may be measured directly by calipering or from measuring the length and computing the cross-sectional area by dividing the bulk volume by the length. These measurements are made before the sample is measured for permeability. If the sample is to be mounted in plastic or pitch, it must be measured before mounting. However, if a mounted core is cut or sectioned to clean the ends, the length must be remeasured after the cutting.

The clean sample is placed in an appropriate holder in the permeameter so that any bypassing of air around the sides of the sample or the mounting is eliminated. Dry air is passed through the core and the rate of flow of the air determined from the pressure difference across a calibrated orifice or other suitable flow-rate measuring device. The differential pressure across the sample may be adjusted to give appropriate or convenient rates of air flow. The inlet air pressure and the air flow rates are recorded. From these measurements and the sample dimensions, the permeability may be calculated. The dry-air permeability may be calculated by the following formula:[11]

$$k = [(2{,}000\ Q_o\ p_o\ L\ \mu) \,/\, (p_i^2 - p_o^2) A] \qquad (14)$$

Wherein:

k = permeability to dry air, in millidarcys.

Q_o = rate of flow, in cubic centimeters per second, of outlet air.

p_o = outlet pressure, in atmospheres (absolute).

p_i = inlet pressure, in atmospheres (absolute).

μ = viscosity of air, in centipoises (see Table 3.5.15T1).

L = length of sample, in centimeters

A = cross-sectional area perpendicular to direction of flow, in square centimeters.

TABLE 3.5.15T1
VISCOSITY OF AIR AT ONE ATMOSPHERE

Viscosity,* μ, in micropoises
(1 micropoise = 10^{-6} poise)

A: Temp., Deg F.	30	40	50	60	70	80	90	100
0	.....	174.0	176.8	179.6	182.4	185.0	187.7	190.4
1	.....	174.3	177.0	179.9	182.6	185.3	188.0	190.7
2	171.8	174.6	177.3	180.1	182.9	185.6	188.3	190.9
3	172.1	174.9	177.6	180.4	183.2	185.9	188.6	191.2
4	172.4	175.1	177.9	180.7	183.4	186.1	188.8	191.4
5	172.7	175.4	178.2	181.0	183.7	186.4	189.1	191.7
6	172.9	175.7	178.5	181.2	183.9	186.6	189.3	192.0
7	173.2	176.0	178.7	181.5	184.2	186.9	189.6	192.3
8	173.5	176.2	179.0	181.8	184.5	187.2	189.8	192.6
9	173.7	176.5	179.5	182.1	184.8	187.4	190.1	192.8
								193.1

B: Temp., Deg C.	0	10	20	30	40
0	171.8	176.8	181.8	186.6	191.4
1	172.3	177.3	182.3	187.1	191.9
2	172.8	177.8	182.8	187.6	192.4
3	173.3	178.3	183.25	188.1	192.9
4	173.8	178.8	183.7	188.6	193.3
5	174.3	179.3	184.2	189.1	193.8
6	174.8	179.8	184.7	189.5	194.3
7	175.3	180.3	185.2	190.0	194.7
8	175.8	180.8	185.7	190.5	195.2
9	176.3	181.3	186.2	191.0	195.7

*Calculated from Sutherland's equation:

$$\frac{\mu}{\mu_o} = \left[\frac{T_o + C}{T + C}\right]\left[\frac{T}{T_o}\right]^{3/2}$$

Wherein: the temperatures are measured above absolute zero (—273 C.), and C is taken as 120 deg for air.† The standard viscosity is μ_o = 183.25 micropoises at T_o = 23 C. = 296 K., based upon independent observations by six investigators, evaluated by Birge.‡

†Montgomery, R. B: *J. Meteorology*, 4, 198 (1947).
‡Birge, Raymond T: *Am. J. Phys.*, 13, 63 (1945).

Calculations may be simplified by any one of several methods. One method is to use specific inlet pressures and such a low pressure drop across the rate-measuring orifice that the outlet pressure is essentially one atmosphere.

The formula then reduces to the following:

$$k = QFL/A \qquad (15)$$

Wherein:

$$F = \frac{2000\ \mu\ p_o}{(p_i^2 - p_o^2)} = \frac{2000\ \mu}{(p_i^2 - 1)}$$ (a constant for each fixed inlet pressure, where p_o = 1 atmosphere)

The viscosity, μ, is the viscosity of air under the conditions used to calibrate the orifice. The permeameter compares the pressure differences across the core and the orifice. Since the same air flows through both, any change in air viscosity from either temperature changes or water vapor will have no effect on the relative pressure readings.

A second method of simplifying calculations involves preparing calibration charts or tables showing the permeance* vs. the outlet pressure for given inlet pressures and orifices. The following formula applies:

$$k_c = \frac{L_c}{A_c}\left(\frac{k_{or}}{L_{or}/A_{or}} \cdot \frac{\Delta p_{or} Q_c}{\Delta p_c Q_{or}}\right) \qquad (16)$$

Wherein:

k_c, k_{or} = permeability of the core and the equivalent permeability of the orifice, respectively, millidarcys.

Δp_c, Δp_{or} = pressure drop across the core and orifice, respectively, atmospheres.

Q_c, Q_{or} = flow rate through the core and orifice, respectively, cubic centimeters per second.

*The permeance, usually referred to as "apparent permeability," is the proper term for flow capacity. Its use is analogous to the term "conductance" for the flow of current through an electrolyte solution. Permeance bears the same relationship to permeability as conductance to conductivity.

L_c, L_{or} = length of the core and orifice, respectively, centimeters.
A_c, A_{or} = cross-sectional area of the core and orifice, respectively, square centimeters.

This equation can be reduced to:

$$k_c = \frac{L_c}{A_c} \cdot \frac{Q_c}{\Delta p_c} \cdot \textit{orifice constant} \qquad (17)$$

A standard permeable plug can be used to determine the orifice constant directly. If one prepares tables or nomographs from measured outlet pressures, p_o, for given inlet pressures and orifices, then the equation can be reduced further to:

$$k_c = \frac{L_c}{A_c} K_c^{\theta} \qquad (18)$$

Wherein: K_c^{θ} is the permeance of the core.

The permeance, obtained as described above, is multiplied by the L/A ratio, or $L^2/bulk\ volume$ ratio of the core to give the permeability k_c.

Further simplifications may be made by the use of nomographs, calibration charts, or tables. The value of μ may be fixed for an average room-temperature condition and p_o may be made equal to one atmosphere.

3.5.15.2 Apparatus

a. Pressure Measurement

The pressure drop across the core sample is measured as shown in Fig. 3.5.15F1. A fixed pressure of dry air between 1 and 80 cm of mercury is supplied using a suitable pressure regulator. Mercury, oil, or

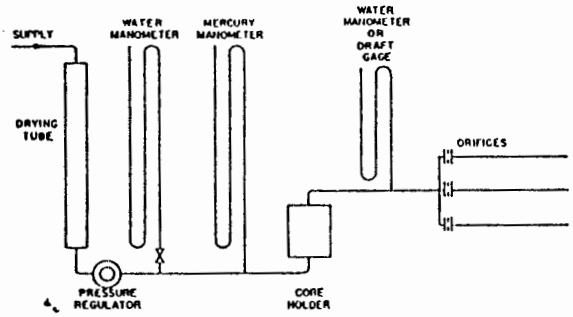


FIG. 3.5.15F1—AIR PERMEAMETER

water manometers may be used to obtain the desired accuracy on the core inlet and outlet pressures. Bourdon-type gages are not reliable and should not be used when attempting to obtain reproducible measurements.

b. Flow-rate Metering Devices

The flow-rate metering devices used are of three types:

1. Calibrated orifices. (A capillary tube which is calibrated for the conditions of testing, so that the pressure drop across the orifice is small compared to the core.)
2. Soap bubble in a calibrated burette.
3. Water-displacement meters.

c. Core Mounting and Holders

Two main types of core holders are used for conventional samples:

1. The Hassler-type (holds cylindrical samples or cores mounted in cylindrical castings or rings), Fig. 3.5.15F2.
2. The Fancher-type (for cylindrical and rectangular samples), Fig. 3.5.15F3.

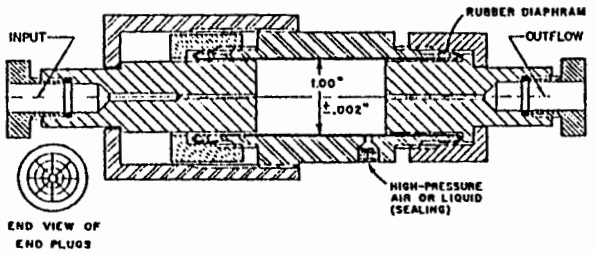


FIG. 3.5.15F2—HASSLER-TYPE PERMEABILITY CELL

The Hassler sleeve-type holder shown in Fig. 3.5.15F2 may be used with cores which are not mounted but are reasonably cylindrical and uniform in cross section, or with cores which have been mounted in potting plastic or supported by pitch in metal or pyrex rings. The sleeve material must be pliable enough to allow complete sealing around the core sample. To accomplish this, a minimum of 100 psi differential between the outside sleeve pressure and the pressure at the inflow face of the sample should be used. For routine-analysis standard practice, using either the Hassler- or the Fancher-type core holder, it is necessary to be certain that the sample is sufficiently strong to prevent deformation by the pressures exerted with the holder. In tests using soft sandstones with a Fancher core holder, it was found that the permeability value depended upon the operator. An

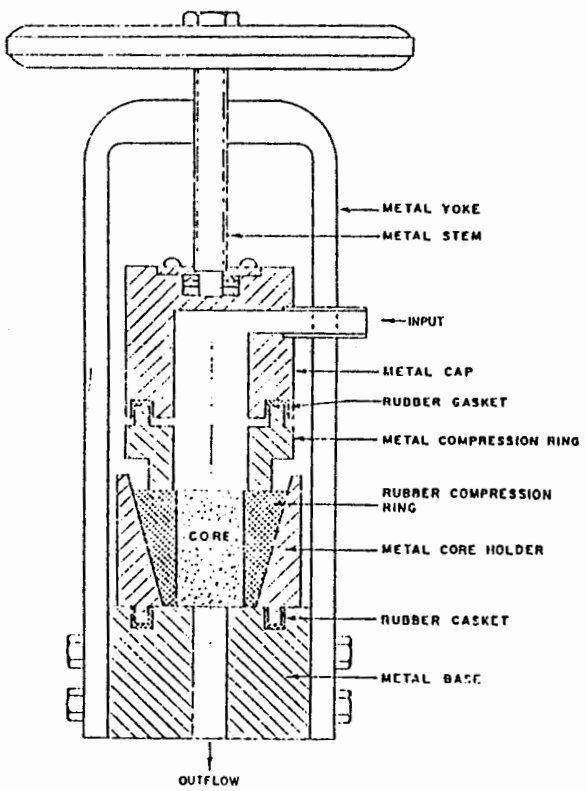


FIG. 3.5.15F3—FANCHER-TYPE CORE HOLDER

appreciable change in permeability was effected, depending upon how tightly the rubber was forced against the core. When such cores were mounted in plastic, metal, or glass rings, and the core surface was effectively sealed, all operators obtained the same permeability values.

If the cores are sufficiently hard and consolidated, they may be run in either the Hassler sleeve or the Fancher holder without support provided by any mounting medium. However, friable, soft, or shaly cores may require mounting. Either optical pitch or a suitable potting plastic may be used for this purpose. The pitch is used to seal the sample in either a metal or pyrex glass ring. The potting plastic may be used to replace the pitch or may be cast around the sample to form a sylindrical mount (see Appendix 3.5.15A1). In any case where a sample is potted or mounted, the Hassler sleeve and the mounting must be such as to insure that the sides of the sample are completely sealed. A compression holder (Fig. 3.5.15F4) may be used instead of the conventional Hassler sleeve for samples mounted in rings. The ends of the core must be clean and open to air flow, and the core must be sealed on the sides to the mounting medium. The permeability measurement is extremely sensitive to the slightest crack. If a crack is suspected, it may be checked by pouring a film of acetone on the surface of the core while the air is passing through it. A row of bubbles may indicate a crack.

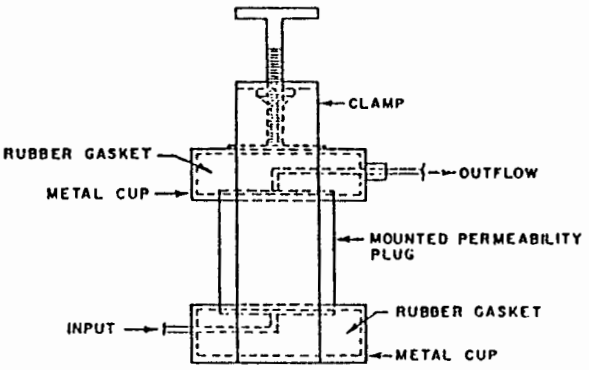


FIG. 3.5.15F4—COMPRESSION CELL FOR RING-MOUNTED CORE SAMPLES

3.5.15.3 Precautions

a. The permeameter shall be checked regularly by means of capillary tubes with various known permeabilities or with standard plugs.

b. Check all cores for cracks or fractures, particularly if high results are obtained. If there are any cracks, samples should be rejected. Mounted samples may be tested for leaks by pressing one face of the ring against a holed rubber stopper fastened to the air supply. Air is passed through the core and, by means of soap and water or acetone, it may be ascertained if the air is issuing uniformly through the end of the core or through a crack. If the air issued uniformly, the air permeability as read was probably correct. If the air issued at one point or crack in the core or between the mounting medium and the core, the result was not satisfactory. If the seal was poor, an attempt should be made to reseal and retest before rejection of the sample. The sample must be thoroughly redried before retesting.

c. The sample holder of the permeameter must be such that when pressure is applied at one end of the system, all flow is through the sample. Care must be taken that no fluid bypasses the sample through an imperfect seal between the sample and the walls of the sample holder or between the sample and the supporting material if it is mounted.

d. Penetration of the mounted samples by the mounting material must be minimized by the choice of material or relatively high melting point or by careful coating of the sample. The sample should not extend beyond the surface of the mounting material. The mounting material should not be allowed to encroach to any extent upon the faces perpendicular to the path of flow. Reference to specific details of one method for sample mounting, as well as mounting materials, can be made to Par. 60 of *API RP 27*.[7]

e. The use of potting material or mounting pitch which is too brittle may tend to pull the cores apart and develop cracks on cooling. Further, the use of temperatures excessively high may burn the mounting material, leading to its decomposition and penetration of the core by some of the constituents. Also, too high a temperature in mounting these cores may result in the alteration of some samples containing clays or other hydratable minerals.

f. The desiccant used in the scrubber to dry the air of the permeameter should be checked frequently and renewed when necessary.

g. The cross section of the samples should be as uniform as possible.

APPENDIX

3.5.15A1 A METHOD FOR CASTING CORE SAMPLES IN PLASTIC

The following procedure has been used by one laboratory for successfully mounting over 50,000 cores. Epon 864 is heated until it becomes a liquid. It is then mixed with 18 percent by weight of the final mixture of dibutylphthalate. When this mixture cools, it has a consistency of molasses and has a long shelf life. Consequently, large batches of about 5 gal are prepared. When cores are to be mounted, about 20 grams of the plasticized Epon for each core are heated to between 120 and 140+ F. It is then quickly mixed with 5 cc of diethylene triamine for each 100 grams of plasticized Epon and poured around the core.

A short section of steel tubing which has been given a slight taper by pressing over a tapered mandrel is used as a core mold. The steel tubing is dipped into 50-percent silicone (Silicone 20) solution to prevent the plastic from sticking to the steel. The plastic-mounted cores are pressed out of the molds after setting by means of a modified bottle capper.

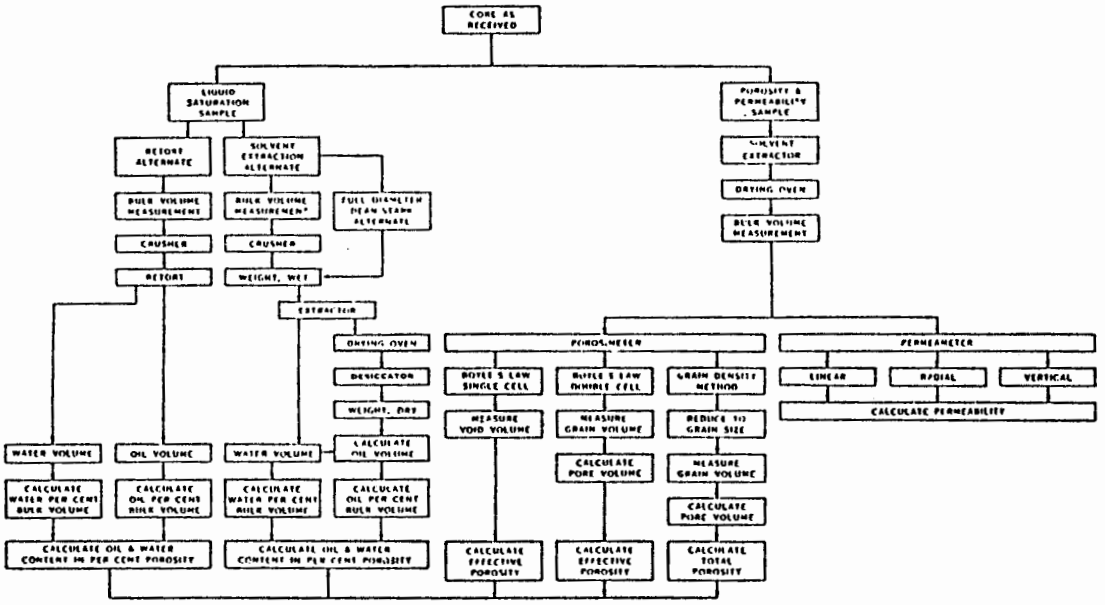
If it is desired to set the plastic rapidly, it may be heated as high as 180 to 190 F. However, if this is done, small batches must be used and the mixing of the diethylene triamine and the pouring accomplished quickly since the plastic will set in 3 to 5 min after the addition of amine.

If the plastic is handled properly, it can be cast around the core so that the penetration is not more than 1 grain thickness. In the cases of very permeable cores mounted with hot thin plastic, some invasion can occur and the penetrated area must be subtracted from the measured cross-sectional area. Some other plastics can be used, but these precautions should pertain.

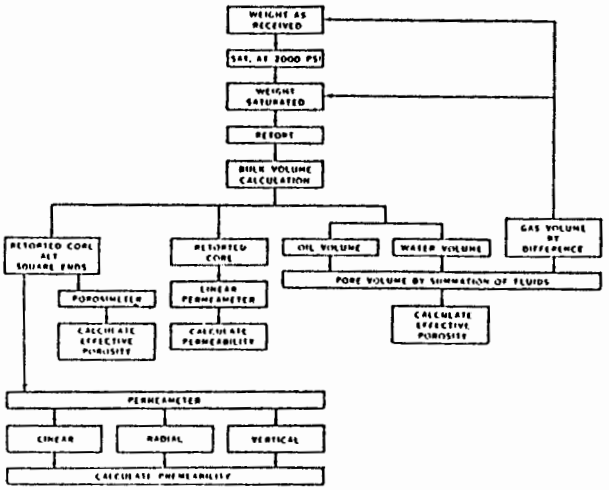
4.0. FULL-DIAMETER CORE ANALYSIS

FULL-DIAMETER CORE-ANALYSIS PROCEDURES

SOLVENT EXTRACTION



VACUUM RETORT



(A schematic flowsheet of the routine core analyses described in Section 4.1.)

4.1 LABORATORY CORE PREPARATION

The preparation of core samples for laboratory analytical procedures must, of necessity, be dependent upon:

a. The data desired on the particular core to be analyzed.
b. The type of rock or formation from which the core was taken.
c. The coring technique involved in cutting and bringing the core to the surface.

For example, if fluid-saturation data are required, the core must be carefully and expeditiously handled in the laboratory so that the fluids in the sample remain relatively undisturbed until the analysis has been undertaken. Many formations contain clays which are susceptible to swelling or chemical reaction when contacted with fresh water, thereby altering the basic characteristics (porosity and permeability) of the rock. Therefore, any fluids which contact the samples during cutting and handling of the sample prior to analysis must not in any way damage the sample or displace any of the native fluids in the sample. Prolonged exposure to sunlight, air, or heat will greatly affect the fluid saturations in the sample prior to analysis. It is, therefore, important that the samples by analyzed as soon as the preservation medium has been removed.

4.11 CUTTING OF SAMPLES

The maximum length of the core sample is dependent upon the apparatus to be used for extraction and the subsequent testing to be done.

4.12 CLEANING OF SAMPLES

Cleaning full-diameter cores requires considerably longer than the time required for conventional core samples. The core is considered to be clean when the solvent or solvents are clear after contact with the sample. If after drying the sample shows oil discoloration, the cleaning process should be repeated.

4.121 Solvents

Prior to the laboratory measurement of porosity and permeability, the original liquids must be completely removed from the core sample. Various solvents used for hydrocarbon extraction purposes, are listed alphabetically.

a. Acetone
b. Benzene
c. Benzene-methyl alcohol
d. Carbon tetrachloride
e. Chloroform
f. Ethylene dichloride
g. Hexane
h. Naphtha
i. Tetrachloroethylene
j. Toluene
k. Trichloroethylene
l. Xylene

The particular solvent to be used should be selected in order not to attack, alter, or destroy the structure of the sample. It should be recognized that the solvents in this list may not be complete solvents for all hydrocarbon constituents in natural cores, but they have been widely used for extracting samples for routine analysis. Some will be more suitable than others for specific uses; e.g., chloroform has been found to be excellent for many Mid-continent crudes, and toluene has been found useful for asphaltic crudes. Carbon tetrachloride may hydrolyze during extraction, forming hydrochloric acid as a product. When subjected to higher temperatures it decomposes, liberating phosgene gas and leaving an insoluble material in the core.

Closed-type electrical heaters should be used whenever inflammable solvents are used. Safety precautions — such as adequate ventilation of the laboratory, accessibility of fire extinguishers, fire buckets, and safety showers — should always be observed. Extraction should be conducted under hoods equipped with forced-draft ventilation.

The various solvents used for extracting core samples can be reclaimed by well-known physical and chemical methods. Such recovery can make more practical the use of an expensive solvent that is ideally suited for a particular extraction.

4.122 Gas-driven Solvent Extraction (U. S. Patent No. 2,617,719)

In this method of cleaning, the core is subjected to repeated cycles of internal dissolved- or solution-gas drive until the core is cleaned of residual oil. This method will clean any porosity, regardless of the type or complexity. It works in a crack or fissure system as well as in pure inter-granular porosity. It is successful in the so-called dead-end or one-opening type of porosity. After solvent extraction the cores are oven-dried to remove residual water and solvent.

Carbon dioxide is excellent for solution gas because of low fire or explosion hazard and high solubility in most solvents. Some of the solvents which can be used are naptha, benzene, toluene, or a mixture of solvents.

Data showing the number of cycles necessary to clean full-diameter cores for four different types of formations are presented in Fig. 4.51F1, which shows a plot of cleaning cycles vs. porosity for an inter-granular type lime, a fractured lime, a relatively clean sand, and a shaly sand. The core samples reported here were cleaned and dried and the porosity determined. They were then subjected to additional cleaning cycles and dried each time until the pore volume showed no increase.

The minimum number of cleaning cycles (5) was required for the clean sand, and the maximum number of 14 was required for the shaly sand. The fractured lime required only 6 cycles, whereas the inter-granular lime required 8. Because of the fracture system, the cleaning solvent was able to penetrate to the center of the core more easily in the fractured lime than in the inter-granular lime which had no fracture system. All samples were broken open after the cleaning experiment and examined under an ultraviolet lamp. There was no fluorescence, which is additional proof of the efficiency of this cleaning process.

The apparatus and procedure are described in 4.51.

4.123 Distillation-extraction Method

The discussion and description of this technique will be found in 4.22 and 4.53.

4.13 DRYING

Full-diameter cores may be dried in:

a. A conventional controlled-temperature oven utilizing a maximum temperature of 240 F.

b. A vacuum controlled-temperature oven utilizing a maximum temperature of 200 F.

All core samples should be dried until the weight becomes constant. The minimum time for drying full-diameter cores may be considerably longer than the 2-hour period used for conventional samples.

4.14 PRECAUTIONS

There are a number of precautions which must be observed in the preparation of all types of samples for routine core measuresments. These are:

a. Core samples containing clays and gypsum must not be dehydrated during preparation.

b. The usual criterion for sample cleanliness is a clean extract, but it must be recognized that many solvents are not complete solvents for all types of oils.

c. Heavy asphaltic oils usually require the cycling of more than one solvent.

d. Care must be exercised in drying samples containing hydrated or hydratable materials and, in some cases, temperatures lower than those indicated in 4.13 must be used.

4.2 FLUID-SATURATION DETERMINATION

Accurate determination of the fluid content and specific fluid saturations of cores is an important element in the interpretation of core-analysis data. Proper care in handling and preservation of the core until analyzed is very necessary to prevent changes in fluid content by drying or contact with water.

Specialized analytical techniques have been developed for the study of core samples of different physical characteristics and different sizes, as obtained by the various methods of coring. Several widely used procedures for determining core fluid saturations provide acceptable data.

4.21 VACUUM OR RETORT METHOD

4.211 Principle

The vacuum distillation or retort method of determining the fluid content of cores is based upon the removal of liquid from a core sample by heating and vaporization under controlled conditions of temperature and reduced pressure. The vapors are condensed, the liquids collected in calibrated glass tubes, and the volume of each liquid is read directly. Before retorting, the gas space is saturated with water. From the volumes of fluids obtained, the fluid saturations of the sample can be calculated with the aid of some other related measurements.

4.212 Data

The weight increase during the saturation step is taken as a measure of the pore volume of the core occupied by gas when the core was sampled. The amount of pore water in the sample is then calculated as the difference between total water recovered and the water injected into the sample during the saturation process. Measured oil-recovery volumes are corrected for vapor losses, cracking, and coking by using appropriate corrections determined from blank and calibration tests. The grain volume of each sample is obtained by dividing the weight of the dry sample by its grain density, determined on a representative portion or available from earlier determination. The sum of the grain volume, the total recovered-water volume, and the oil volume, gives the bulk volume. The volume of pore water, gas volume, and corrected oil volume are expressed first as percentages of the bulk volume as divided each by the sample bulk volume. A summation of these bulk-volume percentages yields the porosity of the sample. The oil and water saturations are calculated by dividing the percent volume of oil and percent volume of water by the porosity of the sample.

4.213 Advantages

a. Large samples can be used, thus providing a more representative section of the formation being analyzed, particularly where the formation is nonhomogeneous because of vugs, fractures, or heterogeneous lithology.

b. The method is relatively rapid.

c. All fluid-content determinations are made on the same sample. Each fluid-content determination is made independently of the others.

d. Samples whose minerals are stable up to 450 F. are not destroyed by the technique.

4.214 Limitations

a. The method is capable of accurate water-content determinations if the sample minerals are stable up to 450 F. If they are not — as in the case of clays, some shales, and gypsum, the water content determinations will be high.

b. Oil correction data should be determined for each crude encountered.

c. Low-gravity crude oils are difficult to distill at the temperatures used.

d. Some coking may occur when retorting weathered cores or cores containing low-gravity crude oils.

The apparatus and procedure are described in 4.52.

4.22 DISTILLATION-EXTRACTION METHOD

4.221 Principle

The method involves distilling water from the sample, condensing it, and accumulating it in a calibrated receiving tube. The oil is removed by solvent extraction and the oil content is calculated from weight-loss data and the water-content data. The method is similar to the distillation-extraction method for conventional core samples, except that the equipment is scaled for the larger core samples.

4.222 Data

The total of the several volumes of water drained from the separator bulb is the water content of the sample. The loss of sample weight, less the amount of water measured during extraction, is the weight of the oil that was contained in the sample. The oil weight is converted to oil volume with the use of the oil density. The oil and water saturations are determined with the use of the foregoing data and with porosity of pore-volume data determined in other tests.

This method lends itself to the determination of pore volume by the summation of fluids method (U. S. Patent No. 2,345,535), with little additional time involved, if the fresh samples are saturated with water before they are extracted. The weight increase during saturation is taken as a measure of the gas content of the sample. The total water extracted from the sample, less the weight increase during saturation, is the water content of the sample. The oil content is then determined (as above); and the summation of the gas, water, and oil content yield the pore volume of the sample.

4.223 Advantages

a. The procedure is simple and requires little attention during the distillation.

b. Relatively low temperatures are normally used and the decomposition of minerals is minimized.

c. Very accurate water-content determinations can be made.

4.224 Limitations

a. A long time may be required to complete the analysis.

b. Grain loss, incomplete water distillation, water gained or lost from the condenser, and incomplete drying may critically affect the oil-content determination.

c. Heating at 240 F. may cause the dehydration of clay minerals or gypsum in the sample. This will also affect the oil-content determination.

The description of the apparatus and procedure may be found in 4.53.

4.23 FLUID SATURATIONS FOR CORES CLEANED BY GAS-DRIVEN SOLVENT EXTRACTION (U. S. Patent 2,617,719)

A sample, adjacent to the section cleaned for porosity and permeability measurements, is crushed and treated by one of the techniques used for conventional core analysis under 3.2. A larger sample of core than that usually used for the conventional routine analysis may be crushed to obtain a more representative sample.

4.3 POROSITY DETERMINATION

Full-diameter core analysis is probably the most reliable method of measuring the properties of heterogeneous formations, such as vuggy or fractured carbonates or laminated shales and sands. These features, however, are those most likely to cause errors in core-analysis measurements. Vugs and fractures limit the accuracy of bulk-volume measurements by liquid-displacement techniques. In samples having distinct variations in lithology, such as mixtures of lime and dolomite, it is difficult to get a representative grain density from such a portion of the sample. Methods used on conventional core samples are generally applicable to full-diameter cores, with some modifications in equipment and technique. The major change required in equipment is a scaling up in size. Some of the procedures lend themselves better than others to dealing with the problems of the larger and usually more heterogeneous samples. With the additional stipulation that the foregoing restrictions apply, the advantages and limitations of the procedures listed under 3.3 can be used as a guide in selecting the proper bulk-volume and pore-volume measuring techniques. The porosity is determined as a ratio of the measured values for the pore volume and the bulk volume.

4.31 BULK-VOLUME MEASUREMENT

The methods most often used and probably most applicable to full-diameter core bulk-volume measurements are: *a*, liquid displacement; *b*, calipering; and *c*, summation of grain volume and pore volume. If the liquid-displacement method is used, care must be taken to fill or cover any vugs or large fractures present on the external faces of the core. This may be done with wax, plastic, clay, or tape. If an actual coating is used, its volume must be subtracted from the apparent bulk volume to yield true core bulk volume. The volume of the coating may be determined either by weighing the core before and after coating and dividing the weight difference by the density of the coating or by routinely measuring the bulk volume of the coating after it has been taken off the core. Further details will be found in 3.314 and 3.3221.

4.32 PORE-VOLUME MEASUREMENT

The pore-volume measurement may be made either as: *a*, total pore volume on a crushed sample; or *b*, effective pore volume on the uncrushed core.

4.321 Total Pore Volume

The total pore volume is the difference between the bulk volume and the grain volume. An accurate grain-density measurement is necessary for calculating the grain volume from the weight of the sample. In heterogeneous core samples, great care should be taken to obtain representative portions of the core for grain-density measurements. In some laboratories where flood-pot analyses are made or radial permeability is measured, a hole is drilled vertically through the center of the core. This drilled-out portion is normally as representative a sample as can be obtained and may be used for grain-density measurement. The procedures for grain-density measurement are described in 3.3211, 3.3212, 3.58, 3.59, and 3.5.11.

4.322 Effective Pore Volume

Many of the conventional core-analysis techniques may be used to determine effective pore volume of full-diameter cores. However, it may be impractical to scale up some of the equipment used in the conventional techniques, e.g., the glassware used in the Washburn-Bunting method. Some procedures may have to be modified to a greater degree than others.

The effective pore volume can be obtained in two ways, viz., by *a*, measuring the grain volume and subtracting it from the bulk volume; or by *b*, measuring the pore volume directly, using a modified Boyle's Law single-cell procedure or summation-of-fluids procedure.

4.3221 Grain-volume Measurement

The grain volume of full-diameter cores can be measured using a Boyle's Law double-cell procedure similar to that described for conventional cores (3.3221 and 3.5.11). Some modification of the apparatus will be necessary to accommodate the larger core sections.

4.3222 Void-volume Measurement

4.32221 Boyle's Law Single-cell Method

A description of a Boyle's Law single-cell procedure, for full-diameter cores, is presented here to illustrate the necessary modification from a conventional core-analysis procedure.

4.322211 Principles

The effective pore volume of a core may be obtained by the use of a single cell in conjunction with a gas-expansion technique. The pore volume is measured with the core mounted between two pistons. Enclosure around the core is provided by a pressurized rubber sleeve. The sleeve is fitted with an opening through which gas is introduced to the core. Pressure readings are made as gas is expanded from a known volume into the core which is originally at atmospheric pressure. The total volume into which the gas is expanded is calculated from these pressure measurements. The pore volume is defined as the difference between this total gas space and the calibrated volume of the cell. This pore volume represents the effective void volume of the core.

4.322212 Advantages

a. This method is highly precise if the system is well-calibrated and sufficient time is allowed for pressure equilibrium.

b. The sample is not damaged or altered.

4.322213 Limitations

a. The procedure is time-consuming.

b. The ends of core must be faced to provide a sample in the shape of a right cylinder.

c. Irregularly shaped cores cannot be measured.

d. Large vugs must be covered with shim stock or filled with clay to serve as support for the rubber sleeve.

The procedure should be accurate to within ±3 percent of the pore volume measured for pore volumes less than 20 cc, ±1 percent or less for pore volumes greater than 20 cc.

4.32222 Summation of Fluids (U. S. Patent No. 2,345,535)

In the determination of effective pore volume by summation of fluids, the recommended technique for full-diameter cores is to obtain both liquid and gas saturations from one piece of core. This permits the use of a larger sample for the measurements. The core is saturated with water before retorting, to measure the gas volume by calculation from the increase in weight during saturation. The pore water is then calculated as the difference between the total water distilled from the sample and the water used to saturate the sample. The pore volume is the sum of the measured gas, water, and oil volumes.

Further details of the procedure can be found in 4.52.

4.4 GAS-PERMEABILITY DETERMINATION

Permeability is a measure of the ability of a porous sample to transmit fluids. Either gases or liquids are used as fluids in permeability measurements. However, liquid permeabilities are not considered routine because of such factors as interaction between rock constituents and liquids and control of bacterial action. Therefore, only gas permeability will be considered in this recommended practice.

The permeability measurement will be standardized using dry air as the gas. If air permeabilities reported for routine core analysis have been corrected, using a standard table of Klinkenberg corrections,[7] then this should be noted specifically in the report. This corrects the gas permeability of a porous medium to the corresponding value for a non-reacting liquid. This correction is most important for samples with low permeability. The direction parallel to the bedding plane will be standardized as the horizontal permeability. Any measurements in other directions, i.e., vertical, should be so specified and the details described.

Samples of hard, consolidated cores are run according to either the conventional or full-diameter scheme, depending upon their nature. Vugular, fractured, or crystalline carbonate rock, fractured and recemented cherts, and laminated shaly rocks are often best handled by full-diameter methods to obtain a more representative permeability value for the interval tested.

4.41 GENERAL PROCEDURE

The core sections selected for testing are cleaned as described in Section 4.1. If the cores have been tested for fluid-saturation measurements, they will not contain water or hydrocarbons and can be used directly for permeability tests. If samples have contained very saline water, it may be necessary to remove salt from the samples before permeability is measured.

Two methods of measuring permeability on full-diameter cores are common. One method, usually referred to as "linear permeability measurement", utilizes either a Hassler-type holder or a compression, ram-type holder to measure horizontal permeability. These units permit vertical permeability measurements if desired. The second method is designated as "radial permeability." In this method the air is admitted to the outside diameter of the core and the rate of flow through the core into a small hole drilled in the center is measured. Measurements of air flow through the sample are made with the orifice-manometer arrangement described for conventional core analysis (see 3.5.15.2b).

4.42 LINEAR PERMEABILITY MEASUREMENT

4.421 Principle

Linear full-diameter core permeability measurements utilize either a Hassler-type holder or a unit employing two rubber cradles and a hydraulic ram (or compression-type holder) to seal the core sample. Screens are used to distribute the air flow uniformly over the upstream section of the core and to allow uniform flow of air from the core. Both procedures are based upon the same principle and yield comparable results. Horizontal permeabilities are normally measured in two directions across the core diameter. If only one direction is measured, it should be with the direction of principal fracturing, if any. The second measurement is normally in a direction perpendicular to the direction of the first measurement. The apparatus and procedures are described in 4.55.

4.422 Advantages

a. The linear full-diameter measurement provides a maximum length for the flow path of the air.

b. Measurements can be made in various horizontal directions giving a better matrix evaluation.

c. Both vertical and horizontal permeabilities can be measured.

4.43 RADIAL PERMEABILITY MEASUREMENT

4.431 Principle

The permeameter consists essentially of a double piston, with the lower piston somewhat larger in diameter than the upper one, so that air pressure applied to the lower chamber will overcome any pressure exerted by air in the upper or specimen chamber.

The faced core specimen with a vertical center hole is sealed in position in the upper chamber by air pressure in the lower chamber. One end of the vertical hole is sealed and the other end is open to the flowmeter. The upstream air is allowed to enter the specimen chamber at measured pressures, the downstream pressure and flow recorded, and the permeabilitity factor calculated from Darcy's radial-flow formula.

Vertical permeabilities may be measured in other full-diameter equipment prior to drilling the center, vertical hole.

Details of the apparatus and procedure may be found in 4.56.

4.432 Advantages

a. The center sample provides material for grain density and porosity measurements.

b. Cores prepared for radial permeability measurements may be used for flood-pot tests.

4.433 Limitations

a. Fractured materials may fall apart when drilled.

b. The length of the sample is restricted to that which may be drilled with a straight hole.

4.5 DESCRIPTIONS OF METHODS FOR ANALYSIS

4.51 GAS-DRIVEN SOLVENT EXTRACTION (U. S. Patent No. 2,617,719)

4.511 Apparatus

Because a diagrammatic sketch is quite complex, reference should be made to the above patent for modifications in the apparatus from that used in conventional core analysis (3.521).

4.512 Procedure

The cores are placed in a high-pressure chamber. The chamber is pressured up with gas to a pressure equal to that of the gas dissolved in the solvent (200 psi). The gas in the chamber is then displaced at constant pressure by the solvent containing the dissolved gas. After the chamber is filled with this solvent, it is pressured by means of a hydraulic pump to approximately 4 or 5 times the pressure of the gas dissolved in the solvent (1,000 psi). When liquid flow into the core ceases, the core chamber is rapidly depressured to atmospheric pressure and the core left submerged in the solvent until most of the gas has flowed from the core. The solvent is then drained from the chamber and the cycle repeated. Pressure and drain periods are repeated until visual observation indicates the cores are clean. This cleaning operation is more effective when the high-pressure chamber is heated to 160 to 180 F. — electrically, by steam, or by hot water.

The cores are then dried in an oven (see 4.13) and inspected again to determine whether further cleaning is necessary. A thorough cleaning is indicated when the cores have no oil stains on the surface after drying.

4.513 Data

Data showing the number of cycles necessary to clean four different types of full-diameter cores at room temperature are shown in Fig. 4.51F1. Samples from formations bearing only gas or distillate, where no oil stains could indicate the degree of cleanliness, have been found to be clean after 3 cycles.

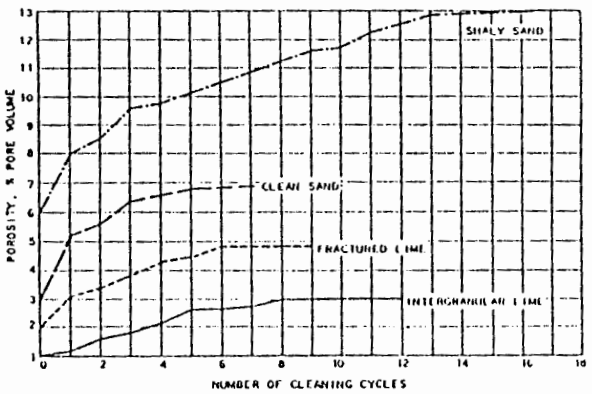


FIG. 4.51F1 — DATA SHOWING NUMBER OF CYCLES NECESSARY TO CLEAN 4 DIFFERENT KINDS OF FORMATIONS

For a relatively clean, permeable core 6 to 8 cycles may be sufficient, depending upon the the nature of the oil in the cores. For low-permeability cores containing low-gravity crude, 20 cycles may be sufficient when the high-pressure chamber is heated; whereas as many as 40 cycles may be needed at room temperature.

Consideration of the type of crude in the sample is always important in determining the number of cycles necessary for cleaning. In any one type of porosity, a low-gravity crude will require more cycles than a high-gravity crude.

4.52 VACUUM-RETORT METHOD

4.521 Apparatus

The equipment to perform the vacuum distillatio process must include a heating chamber which wi contain the sample, a condensing system or col bath, a receiving tube for the liquids, and a vacuu system to the condenser and heating chamber. Fi 4.52F1 presents an example of such a system. Th heating chamber in a system in general use is a aluminum-alloy cylinder whose inside dimensions a 6 in. in diameter and 24 in. long and which is clos at one end. The aluminum cylinder is contained a stainless-steel shell which houses three thermosta ically controlled electrical heating elements. T thermostat control can be adjusted to various te peratures. Normally, 10 such chambers are built one housing. The temperature of each chamber controlled independently and any chamber may removed from the system if not needed. Inside t chamber the core sample is held away from the cha ber walls in a wire-mesh tray to insure better h distribution to the sample and to allow the heav oils to flow unrestricted to the outlet. The open of the chamber is closed with a flat lid containing outlet pipe. The lid is sealed with a silicone rub O-ring and clamped into placed with wingnuts studs.

The outlet tube from the chamber lid conducts flowing liquid and the vapors into a calibrated g receiving tube. The outlet tube and receiving both act as the condensing system. The glass recei tube is maintained in a cold bath of alcohol and ice (temperature approximately —75 F.). At this perature the vapors are condensed or frozen in glass receiving tube.

A vacuum pump connected to the glass recei tube reduces the pressure throughout the distill system. Pressure, as well as temperature, is contr on the system to maintain a proper vaporization A mercury manometer indicates the total pre on the system during the operation.

4.522 Procedure

Prior to the vacuum distillation operation, the is divided into samples of 6 to 22 in. in length. should be taken during sampling to prevent fra ing of the core. The samples are marked for iden tion and weighed to obtain the unsaturated or n weight. The samples are evacuated to remove t and are then saturated with deaerated water pressure of 2,000 psig. Evacuation periods o

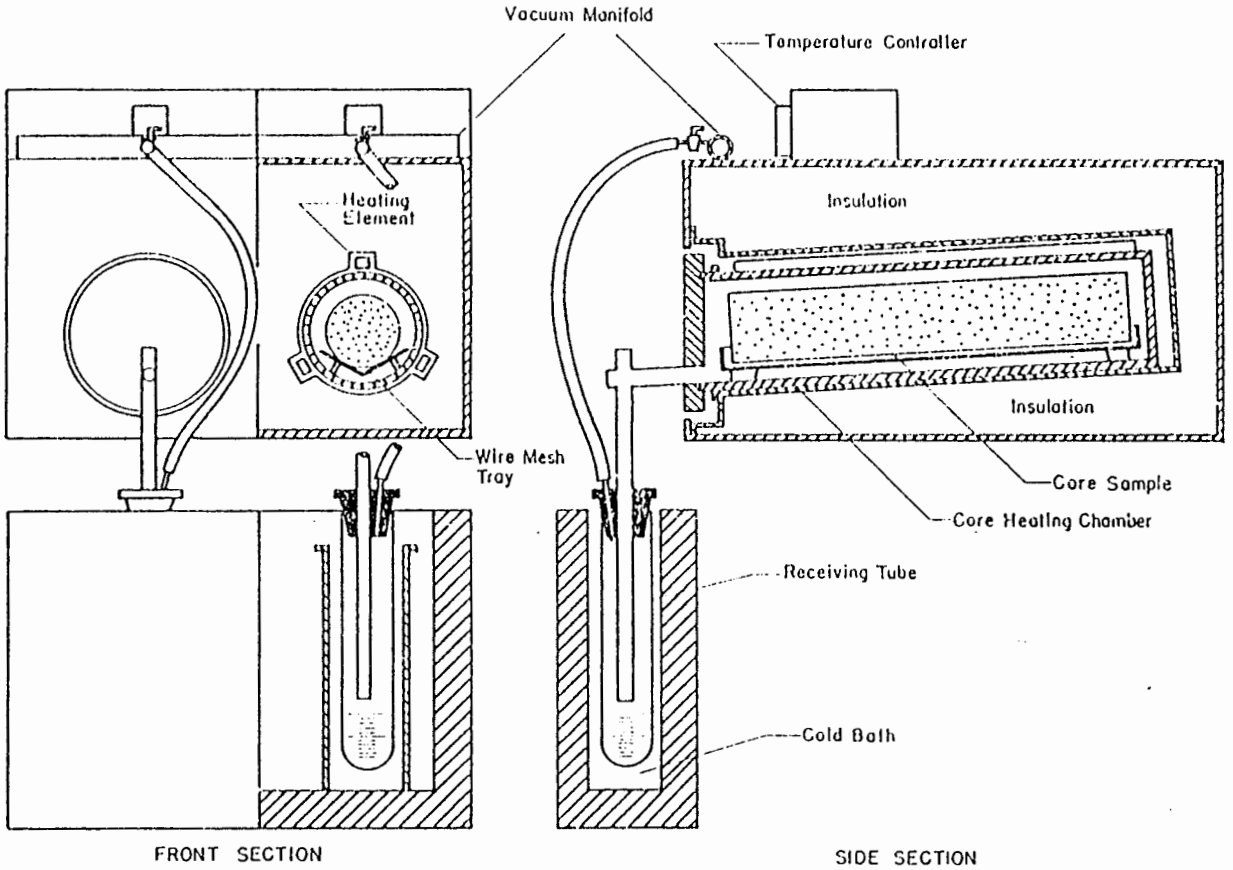


FIG. 4.52F1 — VACUUM RETORT

10 min have been found adequate to reduce the pressure to that of water vapor at ambient pressure. Further evacuation may cause volatile liquids to be lost from the core. Water-saturation periods vary from ½ to 1 hour, depending upon the permeability characteristics of the samples. The samples are removed from the saturator, and the weights of the saturated samples are obtained.

The samples are then placed in the vacuum distillation apparatus. The lids are checked for proper vacuum sealing and then tightened with wingnuts. A calibrated glass receiving tube is placed on the outlet pipe and the alcohol cold bath is raised to cover the glass tube. The alcohol bath must be approximately —75 F. before the beginning of the heating operation. Pressure on the chambers is reduced by using the external vacuum pump. The distillation process may be varied somewhat for the type of sample, but usually the temperature is controlled at approximately 300 F. and the pressure in the chamber is maintained between 200 mm Hg and 300 mm Hg at the beginning of the distillation process. This condition in the chamber is held until the bulk of the sample fluids are distilled over, which usually is within 2 hours. The temperature is then increased to approximately 450 F. and the maximum vacuum applied until all the liquids are distilled or flow out. The distilled fluids are condensed and collected in the calibrated glass receiving tubes which are maintained in the alcohol-dry-ice bath. Because of the extremely low temperature, the water and oil are frozen and essentially no vapor is carried into the vacuum system. The total distillation time varies from 4 to 8 hours, depending upon the characteristics of the samples. After distillation has been completed, the receiving tubes are removed and thawed in a warm-water bath. The water bath must be warm to prevent breakage of the glass receiving tubes by expansion of the ice. The volumes of water and oil obtained from each sample are recorded. The samples are weighed after the vacuum distillation is completed to obtain the "dry weight".

4.53 DISTILLATION-EXTRACTION METHOD

4.531 Apparatus

Fig. 4.53F1 illustrates an apparatus used for the distillation of the core samples. It consists of an electrically heated oil bath, a chamber to contain the core sample and solvent, an offset condenser to condense the water and solvent vapors, and a refluxing trap that will allow the condensed solvent to reflux into the core chamber. The individual sample chambers may be placed in separate heating baths, but normally several of them are placed in a common heating bath. The sample chamber is usually made of aluminum tubing with an inside diameter of 5 to 6 in., depending upon the maximum size of core analyzed. The length of the pot is normally from 15 to 24 in. The bottom end is closed with a welded plate and the top has a flange for bolting on the lid.

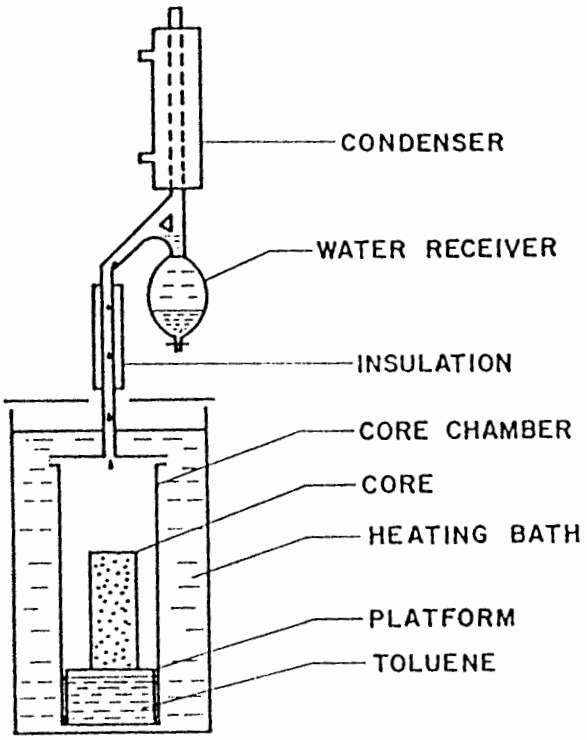


FIG. 4.53F1 — DISTILLATION EXTRACTION APPARATUS

The lid is bolted to the chamber. A gasket between the two sections provides a vapor-tight seal. The chamber lid, in turn, is connected to the condenser-trap assembly with a gasketed union. The lower portion of the condenser is wrapped with insulation to prevent premature condensation of the vapors.

A glass separator bulb is normally used to collect the distilled and condensed water since the volume of water distilled from the core sample is often large. The water collected in the separator is drained from time to time. Care must be taken to prevent water hang-up in the condenser and trap. The inside of the bulb may be coated with a silicone compound to eliminate or minimize hang-up of water. A calibrated glass receiving tube is used to measure the volume of water drained from the bulb. With smaller samples, a calibrated receiving tube can be used in place of the separator bulb.

4.532 Procedure

The core is divided into samples 6 to 22 in. in length. The samples are marked for identification and weighed to obtain the wet weight. The samples are placed into the core chamber. Enough clean, water-free toluene is added to the chamber to insure good refluxing action. A gasket is placed on the chamber flange, and the lid is bolted in place. The loaded chamber is placed in the heating bath and is connected to the condenser-trap assembly. The temperature of the heating bath is raised to approximately 240 F. As it becomes necessary, water is drained from the separator bulb into a calibrated receiving tube, and the water volume is recorded. The process is allowed to continue until 1 cc of water, or less, is distilled from the sample in a 24-hour period. This may require from 3 days to 3 weeks. The core chamber is then taken from the heating bath and opened. The core is dried in an oven to remove the solvent from the sample. The dry weight of the sample is taken.

4.54 BOYLE'S LAW SINGLE-CELL METHOD FOR POROSITY

4.541 Apparatus and Equipment Calibration

a. Rubber-sleeve cell with hydraulic jack.
b. Reference volume and manifold.

Two separate volumes from which gas can be expanded into the core may be used. These gas sources are the manifold and the reference volume shown in Fig. 4.54F1. A steel nipple or pipe with one end capped may be used for the reference volume. The manifold may be made up of small metal tubing and various fittings. The chamber for the reference volume must be independently calibrated. This can be done gravimetrically with distilled water. This chamber may then be used to calibrate the manifold by

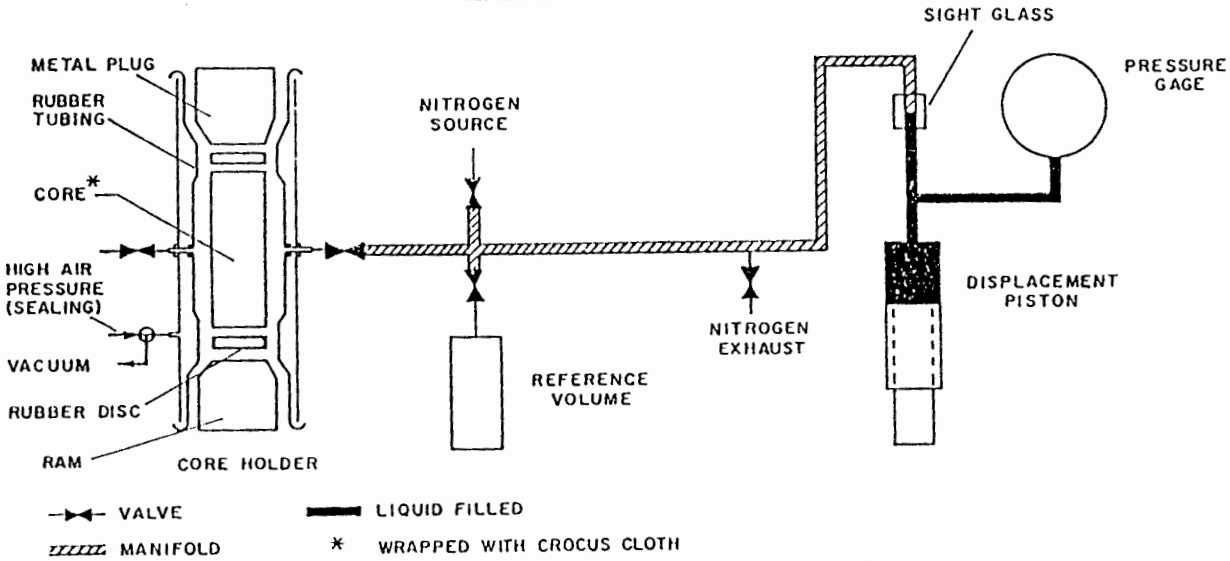


FIG. 4.54F1 — PORE-VOLUME APPARATUS

means of gas expansion. If temperature fluctuations in the laboratory are not great, temperature corrections may be negelected. The combined volumes of the manifold and reference volume, or the manifold volume alone, should approximate the pore volume to be measured. This allows pressure measurements to be made within the most accurate limits of the gage while obtaining a maximum pressure drop.

c. Gage level indicator and displacement piston.

The gage level indicator is a plastic block with an etched reference line. The oil level in a line connecting the block and gage indicates the contraction and expansion of the Bourdon-tube pressure gage. A displacement piston is placed between the level indicator and the gage so that the oil level may be held constant at the etched line. This insures a constant manifold volume.

d. Pressure gage (normally 0-100 psi Bourdon-tube test gage).

e. Vacuum source.

A vacuum is normally applied to the outside of the sleeve whenever it is moved relative to the core and the pistons. This provides greater clearance between the sleeve and the core, thus protecting the sleeve from damage.

f. Crocus cloth.

This is to aid distribution of the gas over the surface of the core in order to reduce the time required for pressure equilibrium. It is prepared by rubbing it against a similar sheet to remove the rough grit surface. The pore space in the cloth is approximately 0.075 to 0.08 cc per sq in. Therefore, the area of the cloth surrounding a core must be measured to determine the volume contributed by it in the cell.

g. Regulated source of pressure.

Dry, clean nitrogen may be used since the compressibility factor remains essentially unity over the temperature and pressure ranges involved in the test.

4.542 Procedure

The core to be tested is cut in the shape of a right cylinder. The sides are wrapped with crocus cloth, to within ½ in. of each end. The crocus cloth may be held in place with rubber bands. The area of the crocus cloth is then measured.

The cloth is placed in the Hassler-type cell which is equipped with two pistons, one of which is operated by a hydraulic jack. Two circular rubber pads, approximately ¼ in. thick, are placed on either end of the core and the assembly is mounted between the two pistons. The section of cell containing the rubber sleeve, which is fitted with a nipple through which the gas is expanded to the core, is placed around the core. The valve connecting the cell and the manifold is closed (see Fig. 4.54F1). The outlet valve on the cell is opened to the atmosphere. Pressure is then applied incrementally and concurrently to the outside of the sleeve and to the hydraulic jack in order to equalize the pressures applied to all surfaces of the core. A sleeve pressure of 300 psi is normally sufficient to seal the core. The jack pressure should be at least 100 psi greater than the sleeve pressure.

Gas pressure between 60 and 70 psig is introduced into the manifold and reference volume system. The oil in the sight glass is adjusted to the etched reference line by means of a displacement piston. The valve connecting the pressure source to the system is closed, and the pressure existing in the known volume of the system is recorded as P_1. The outlet valve of the cell is closed and the inlet valve, which connects the cell to the rest of the system, is opened, thereby admitting gas to the core. Sufficient time should be allowed for the establishment of pressure equilibrium. The time needed to reach pressure equilibrium varies with different cores of the same apparent horizontal permeability. This variation depends upon position, number, and size of fractures and vugs as well as on the permeability of the rock matrix. Normally, cores having an average horizontal permeability of 0.1 md reach pressure equilibrium in 15 to 20 min. Cores having a permeability of 0.1 md, or greater, reach pressure equilibrium in 10 min or less.

The position of the oil in the sight glass is again adjusted to the etched reference line and the final stabilized pressure is recorded as P_2.

4.543 Calculations

To calculate the gas volume in the cell the following formula is used:

$$V_2 = [V_1(P_1 - P_2)]/P_2 \qquad (19)$$

Wherein:

V_2 = total gas volume, in cell and core, cc.
V_1 = reference volume and manifold volume, cc.
P_1 = inital pressure of the gas in the known volume, psig.
P_2 = final pressure of the gas in the entire system, psig.

Since V_2 = *total gas volume*, then:

$$V_p = V_2 - V_c - V_k \qquad (20)$$

Wherein:

V_p = pore volume, cc.
V_c = pore volume of crocus cloth, cc.
V_k = calibration volume for the necessary valve stems and connections to the cell, cc.

The ratio of the pore volume and the bulk volume of the core, multiplied by 100, yields the effective porosity of the sample.

4.544 Precautions

a. Allow sufficient time for core to reach atmospheric pressure after applying sleeve pressure and at conclusion of test.

b. Allow sufficient time for system to reach final stabilized pressure before recording P_2.

c. Calibrate manifold volume whenever fittings are changed or alterations made.

d. Check frequently for leaks.

e. No visible gaps should exist between the ends of the core and the rubber pads.

4.55 LINEAR PERMEABILITY MEASUREMENT

4.551 Preparation of Sample

Samples which have been removed from the drying oven following the cleaning operation (see 4.12) are cooled to room temperature and marked to indicate inlet- and outlet-screen positions. The core samples are then measured by a micrometer to determine diameter and length. If rubber gaskets are used to seal the ends of the core, a diamond saw is used to make a smooth horizontal cut of each end. A square cut of this type is also required for vertical premeability measurements. When horizontal permeability only is needed, and the ram-type holder is used, the ends of the sample may be sealed by dipping them in a molten plastic material which solidifies after cooling. Appropriate-size screens are attached diametrically opposite each other by light rubber bands and then the core samples are placed in the holder. Each screen will cover one quadrant of the core circumference.

4.552 Apparatus

The holder may be either a permeameter as shown in Fig. 4.55F1, known as the compression (ram) permemeter, or Fig. 4.55F2, usually referred to as the Hassler-type permeameter.

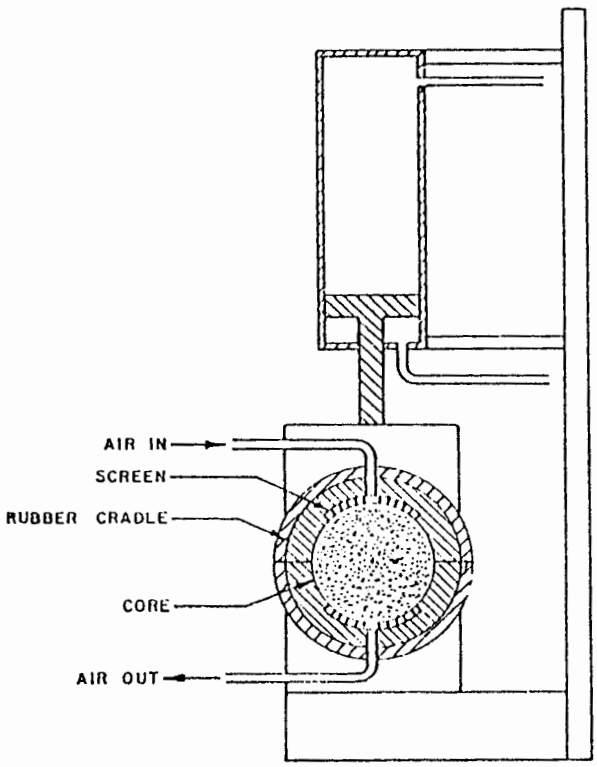
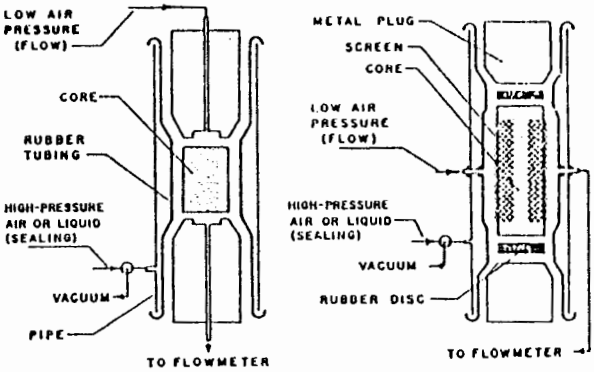


FIG. 4.55F1 — COMPRESSION (RAM) PERMEAMETER



(A) VERTICAL FLOW (B) HORIZONTAL FLOW

FIG. 4.55F2 — HASSLER-TYPE PERMEAMETER

The ram permeameter may be used with cores which have the ends sealed with plastic that are overlapped by the compression halves lined with soft rubber. This completely seals the outside of the core except the area covered by the screens. Air is admitted and removed from the core by two screens placed on diametrically opposite quadrants of the core sample. Permeability is normally measured in two directions — one giving the maximum value (normally along the direction of principal fracturing), and the other at 90 deg to the maximum.

The Hassler-type permeameter consists essentially of a length of steel tubing carrying a rubber sleeve in the interior. The sleeve is attached to the tubing at each end in such a way as to seal the annular space between the tube and the sleeve. Two flow tubes, diametrically opposite, allow flow across the core sample. A hydraulic ram compresses rubber gaskets which seal the ends of the sample. The rubber sleeve is pressured to seal surfaces of the cores except where the screens are positioned. Permeability is normally measured in two directions—one giving the maximum value (normally along the direction of principal fracturing), and the other at 90 deg to the maximum. Vertical permeability is determined by use of this same apparatus by removing the screens from the sides of the cores and replacing the end plugs and rubber disks with perforated end plates and rubber rings for admitting air to the core end. The vertical permeabilities can be measured by selecting the correct inlet and outlet connections.

4.553 Procedure

The measurement of air-flow rate through a sample is then taken intermittently for a period of 3 to 10 min until the flow becomes constant. Flow rates are controlled to minimize turbulence. The maximum rate is limited by the permeability and size of the sample. The rate of air flow is measured by means of a calibrated orifice and water or mercury manometer. An alternative method is measurement in the downstream outlet by timing a soap-film movement in a burette. The calculation of air permeability takes into account the cylindrical shape of the sample, the length of the sample, and the size of the screens through which the air is introduced and removed.

4.554 Calculations

Full-diameter core horizontal permeability is calculated from Darcy's equation, which has been modified by the substitution of a "shape factor." The shape factor, which can be derived from electrical models flow tests, and geometric analysis, is based upon the diameter of the sample and the arc width of the screens used to distribute the air. The Darcy equation for linear gas flow in 3.5.15 is modified to the following form:

$$k = (Qm\mu/L\Delta P)\ (1{,}000)\ (G) \qquad (21)$$

Wherein:

k = permeability, millidarcies.
Qm = volume rate of air flow at mean core pressure cc per sec.
μ = viscosity of gas, centipoises.
L = length of sample, centimeters.
ΔP = pressure drop across core, atmospheres.
G = shape factor (when screen covers 90-deg section of the core, $G = 1.0$). The shape factor G is based on the arc width of the screens and the core diameter.[12] (See Fig. 4.55F3.)

Vertical permeability is calculated from the normal Darcy equation.[11]

4.555 Precautions

a. The permeameter should be checked regularly by means of standard samples.

b. Care must be taken that all flow is through the sample and that no gas bypasses the sample because of an imperfect seal between the sample and the sample holder. If the ends of the sample are sealed by dipping in plastic, the plastic must remain sufficiently flexible to prevent cracking and bond firmly enough to prevent loosening or bypassing of air during the test.

c. The desiccant used in the scrubber to dry the air to the permeameter must be checked frequently and renewed when necessary.

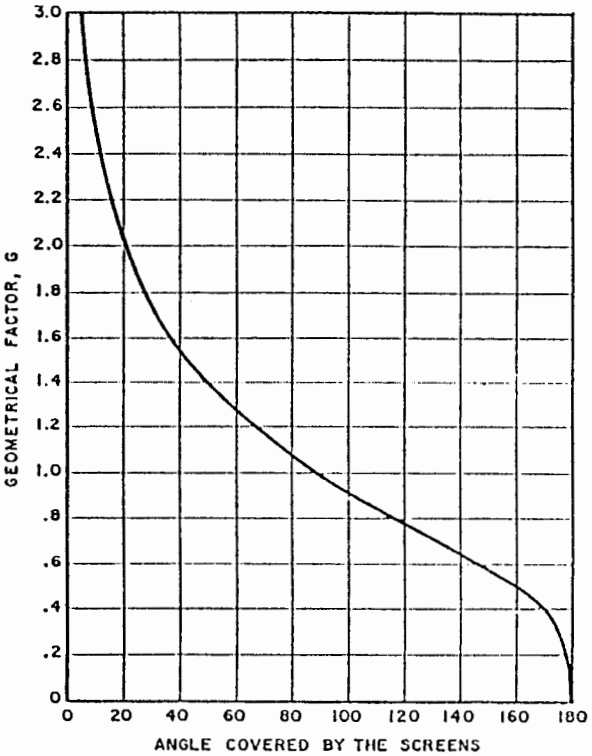


FIG. 4.55F3—THEORETICAL CURVE RELATING THE GEOMETRIC FACTOR AND THE ANGULAR SEGMENT OF THE CORE COVERED BY THE SCREENS

[Collins, R. E: *J. Appl. Phys.*, 23, 681 (1952)]

d. Care must be taken that the screens remain in proper position during compression before making permeability measurements.

e. When using the Hassler-type holder, always apply vacuum to the sleeve before moving the body of the cell.

4.56 RADIAL PERMEABILITY MEASUREMENT

4.561 Apparatus

The full-diameter radial permeameter consists of three parts: The cell, which is sufficiently large to maintain a uniform inlet pressure; the piston to apply a sealing force; and the floating plate assembly which consists of a lower fixed plate, a pivot ball, three springs 120 deg apart, and the upper floating plate. (See Fig. 4.56F1.)

4.562 Procedure

The core is placed on a 1-in. solid rubber gasket which is attached to the lower floating plate. The core is then raised against the closed lid, the center hole of the core matching that of the upper gasket. As the piston pressure increases, the lower floating plate automatically adjusts if the ends are not parallel.

To check for an air leak between the ends of the core and the rubber gaskets, the piston pressure is increased. A decrease in the flow rate indicates that a leak had existed. This test is then repeated until no change in the flow rate is noted.

The rate of air flow is measured by means of a calibrated orifice and water manometer. The air-flow rate is taken after successive readings indicate a

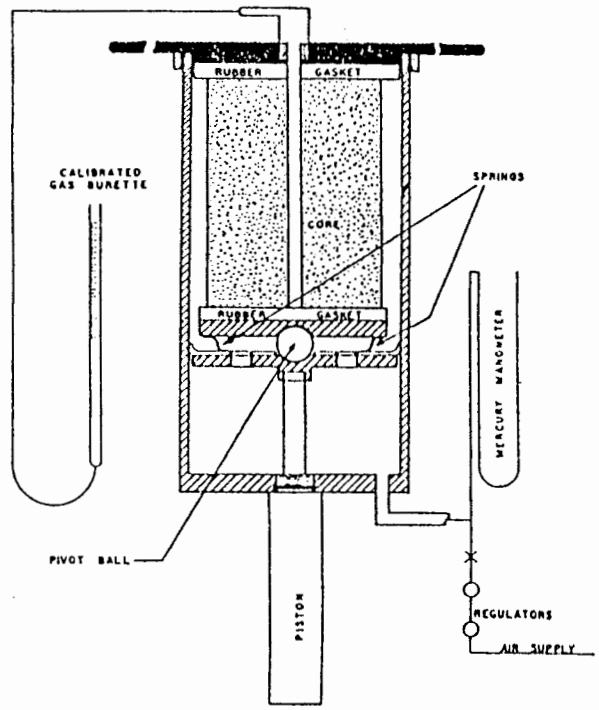


FIG. 4.56F1—FULL-DIAMETER RADIAL PERMEAMETER

stabilized flow. An alternative method is measurement in the downstream outlet by timing a soap-film movement in a burette.

4.563 Calculations

The radial permeability of the core specimen is calculated directly from Darcy's radial-flow equation. Since the height of the specimen and the height of the surface subjected to pressure are identical, there is no "shape factor."

The dry-air permeability can be calculated from the following Darcy radial-flow equation of gas.[11]

$$k = [(\mu Q_a)\ (\ln de/dw)\ (p_o)/(\pi\ h)\ (p_i^2 - p_o^2)][1{,}000] \quad (22)$$

Wherein:

k = permeability, millidarcies.

μ = viscosity of the air, centipoises (at test temperature).

Q_a = measured rate of flow, cc per sec (at test temperature and at pressure = p_o).

dw = inside diameter of inner hole, centimeters.

de = outside diameter of sample, centimeters.

p_i = pressure at inlet to core, atmospheres (absolute).

p_o = pressure at outlet of core, atmospheres (absolute).

h = height of sample, centimeters.

If p_o = *1 atmosphere* and the orifices are calibrated over the range of inlet pressures, the calculation is simplified. The Darcy radial-flow equation may then be used in the following form:

$$k = [\mu Qm\ (\ln de/dw)/2\pi h\ \Delta_p]\ [1{,}000] \quad (23)$$

Wherein:

k = permeability, millidarcies.

μ = viscosity of air, centipoises.

Qm = volume rate of air flow at mean core pressure, cc per sec.
de = outside diameter of sample, centimeters.
dw = inside diameter of center hole, centimeters.
h = height of sample, centimeters.
Δp = pressure drop across the sample, atmospheres (absolute) = $(p_i - p_o)$.
ln = logarithm to the base e.

4.564 Precautions

a. The sample should be drilled on center.

b. The sample should be inspected carefully to determine whether any cracks or splintering of the sample occurred during drilling.

c. The permeameter should be checked regularly by means of standard samples.

d. Care must be taken that all flow is through the sample and that no gas bypasses the sample because of an imperfect seal between the sample and the sample holder.

e. The desiccant used in the scrubber to dry the air to the permeameter must be checked frequently and renewed when necessary.

5.0 SMALL-SAMPLE ANALYSIS

Small samples, such as large cuttings or percussion-type sidewall samples, can *only approximately approach* conventional or diamond-core samples in providing quality and quantity of formation for analysis. In view of the inherent deviations in a vertical section of any formation, several samples should be obtained from each zone if it is sampled at all. In many instances, particularly in exploratory drilling where a normal coring program may not be practical, small samples provide valuable qualitative information on formation properties which cannot be obtained in any other way after the formation has been drilled. Analytical methods have been improved with the marked increase in the amount of small-sample coring, and some measurements of the physical properties of small samples as received can now be made with satisfactory accuracy. Evaluation and interpretation of small-sample data are strengthened greatly if made with full knowledge and understanding of the properties measured with any of several available electric logs. Similarly, experience has shown that the small-sample data are an extremely important aid in proper electrical-log interpretation.

5.1 LABORATORY CORE PREPARATION

Samples too small for analysis by conventional means have limited value in respect to quantitative determinations. These include sidewall samples, chips, and bit cuttings.

5.11 CUTTING OF SAMPLES

Small samples and sidewall samples may require special handling and their laboratory preparation will be discussed in connection with the tests.

5.12 CLEANING THE CORES

The extraction of small core samples may be accomplished as described in 5.52.

5.13 DRYING

The drying of small core samples usually can be achieved in:

a. A conventional controlled-temperature oven utilizing a maximum temperature of 240 F. for a minimum of 2 hours.

b. A vacuum controlled-temperature oven utilizing a maximum temperature of 200 F. for a minimum of 2 hours.

All core samples should be dried until the weight becomes constant.

5.2 FLUID-SATURATION DETERMINATION

5.21 RETORT METHOD AT ATMOSPHERIC PRESSURE

(Use of downdraft retort covered by U. S. Patents No. 2,282,654 and 2,361,844)

5.211 Principle

The method involves removal of the total fluid content of the sample by heating at atmospheric pressure, condensing the vapors, and collecting the recovered liquids in a calibrated receiving tube. The method is very similar to the conventional method of retorting at atmospheric pressure, but the sample cups and liquid receiving tubes are greatly reduced in size to provide accuracy with the small amounts of materials involved (Fig. 5.21F1).

5.212 Data

The oil, water, and gas contents are calculated in terms of percentage of the bulk volume from the volumes of fluid recovered from the retorting and the bulk volume of the sample. The use of properly determined oil and water distillation correction curves permits determination of oil content to within 5 percent and of the water content to within 3 percent of the values measured. Examples of the water and oil calibration curves are shown in Fig. 5.21F2 and Fig. 5.21F3.

5.213 Advantages

a. One segment of sample used to determine gas, oil, and water content.

b. The method is fairly rapid.

c. Each measurement is made directly and independently of others.

5.214 Limitations

a. The distilled liquids tend to form emulsions.

b. Considerable care is required to obtain proper water calibration.

c. Very small amounts of oil may be difficult to determine accurately.

The apparatus and procedure are described in

5.22 PENTANE EXTRACTION METHOD

5.221 Principle

The total oil content of the core sample is extracted by successive addition and decanting of small quantities of pentane. The pentane is then removed by evaporation in a constant-temperature bath, and

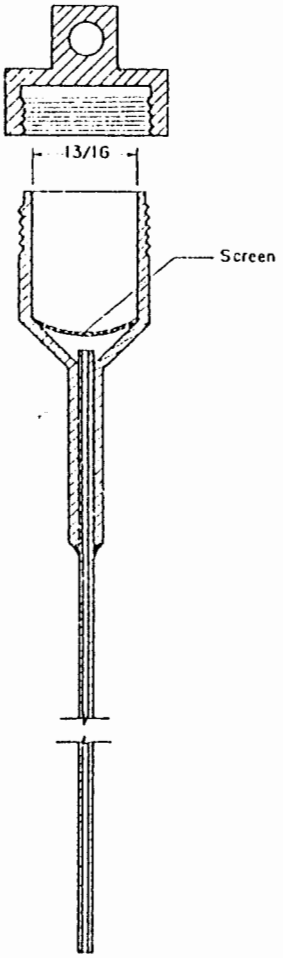


FIG. 5.21F1—RETORT CUP—SIDEWALL SAMPLE

recovered-oil volume is read directly in the calibrated evaporation tube. The water content is calculated from a material balance.

5.222 Data

The volume of recovered oil is corrected for excessive losses with the pentane, or for failure to remove all of the pentane by comparison with calibration curves, as shown in Fig. 5.52F2. The water content is then calculated as a percentage of the bulk volume of the sample by a material-balance equation, as shown in 5.523.

Oil content may be determined with an average error of ±4.5 percent of the measured volume if proper calibration charts are used. The average error in the calculated water content is of the order of ±7 percent of the measured volume.

5.223 Advantage

a. The method is rapid, and reasonably accurate results are obtained.

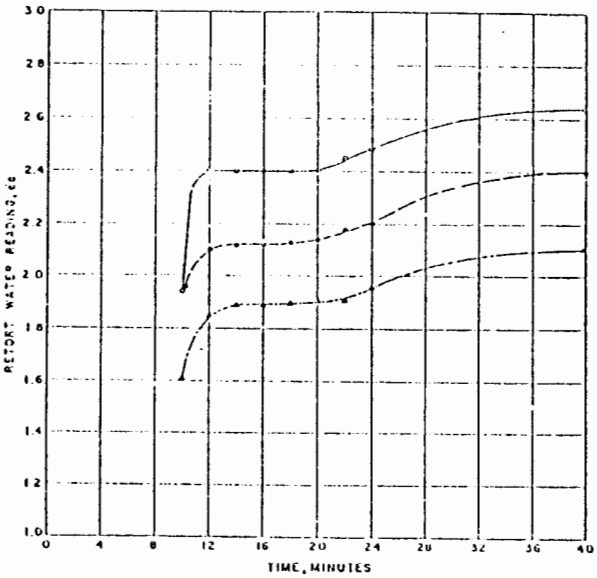


FIG. 5.21F2—WATER-CALIBRATION CURVES

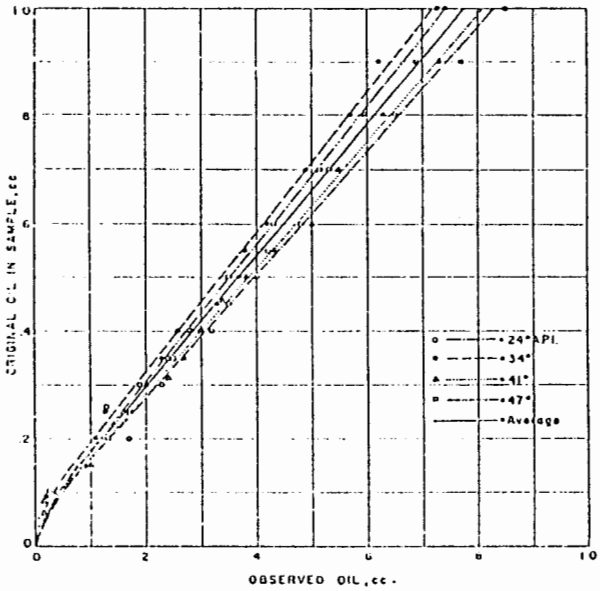


FIG. 5.21F3—OIL-CALIBRATION CURVES FOR SIDEWALL RETORT CUPS

5.224 Limitations

a. Results are sensitive to operator technique.

b. Wide variations in crude-oil properties may require calibration for various temperatures of evaporation bath.

c. Errors in grain-density value or in measurement of gas or oil content contribute to errors in calculated water content.

The apparatus and procedure are described in 5.52.

5.3 POROSITY DETERMINATION

Bulk volumes and porosities can be obtained on small samples with the same methods used in conventional core analysis. In order to effectively handle the smaller sample, it may be desirable to scale down some of the conventional apparatus. Even this scaling down may not be necessary for some equipment, however, since such apparatus as the Boyles' Law double cell, wherein the ratio of sample volume to sample-chamber volume may be critical, can be modified by simply adding steel blanks of known volume to help fill up the chamber.

The same limitations need not apply to all small samples since, for instance, some may be large enough to cut into regular shapes for calipering while others may not.

Procedural changes are greatest in the summation-of-fluids method (U. S. Patent 2,345,535), two modifications of which are presented following.

5.31 RETORT METHOD

In the retort method, the sample is cleaned of mud, placed in a mercury pump, and its bulk volume determined. The gas content of the sample is obtained by injection of mercury (see 3.533). This mercury-injected sample is then placed in a small, specially designed retort cup for distillation of liquid content. The mercury, water, and oil are retorted from the sample and condensed into a graduated collecting tube. Addition of a few drops of emulsion-breaker solution and centrifuging gives good separation of the liquids and permits accurate direct reading of their volumes. Porosity is calculated by summation of fluids (see 3.3222).

The average error in oil saturation is about ±5 percent of the saturation value. Average error in water saturation is less than ±2.5 percent of the saturation value.

A major advantage offered by this analysis is that gas content, oil content, and water content are all measured directly and on the same piece of rock.

For further details see 5.21 and 5.51.

5.32 PENTANE EXTRACTION METHOD

In the pentane extraction method of analysis, the sample is accurately weighed, and the bulk volume and gas content are obtained with the mercury pump (see 3.533). The mercury-injected sample is crushed and washed with pentane to remove its oil content. The pentane is evaporated from the oil-pentane mixture by a hot-water bath, and the volume of extracted oil is measured. The oil content, weight, and bulk volume of the core are then known. By using a measured or assumed grain density for the material, a balance can be set up in which the only unknown is water content of the sample. After the water content has been calculated, the gas content, oil content, and water content are added for total pore volume. The average error in oil saturation is ±4 percent of the saturation value, while the average error in water saturation is ±7 percent of the saturation value.

Further details may be found in 5.22 and 5.52.

5.4 GAS-PERMEABILITY DETERMINATION

Permeability of sidewall samples and poorly consolidated cores which can be hand-shaped and mounted in a holder may be measured by the techniques described for conventional core analysis (see 3.4). Extreme caution should be taken to check for cracks, invasion by mud solids, compaction, or rearrangement by sampling and handling, etc. Completely unconsolidated samples must be handled by special techniques which do not apply to routine analysis.

Tests indicate that sidewall samples taken by percussion may increase in permeability through gr fracture, even though porosity may decrease throu compaction of the pore spaces. Also, one must gu against possible plugging from mud particles dri into the formation as it is sampled.

Permeability of chips and other fragments h been measured by mercury injection using empir correlation charts.[13]

5.5 DESCRIPTION OF METHODS FOR ANALYSIS

5.51 RETORT METHOD AT ATMOSPHERIC PRESSURE

(Use of downdraft retort covered by U. S. Patent 2,282,654 and 2,361,844)

5.511 Apparatus

An example of the small sample retort cup is shown in Fig. 5.21F1. A similar cup with an inside diameter of 1⅛ in. should be used for 1-in. diameter samples. These sample-holder cups are used in an electrically heated furnace, of either the single- or multiple-unit type shown in Fig. 3.53F1 and 3.53F2. The condensing tube passes through a water bath, and the recovered liquids are collected in a small, calibrated receiving tube. A volumetric mercury pump is utilized to obtain sample bulk volume and gas content prior to retorting.

5.512 Procedure

Normally, the small sample is divided into two portions, one to be used to determine permeability and the remainder to be weighed and used in determining fluid saturations. This latter portion may vary from 4 to 15 grams. The bulk volume of the unextracted sample is obtained in a volumetric cury pump. Mercury is then injected into the volume occupied by gas or air by increasing the sure within the mercury pump. The volume of cury injected at 750 psi to 1,000 psi (depending the properties of the sample) is taken as the volume occupied by gas or air (see 3.533). The ple containing residual oil, water, and mercu broken open in the cap of the retort cup to not type of mercury penetration, and then it is ret at atmospheric pressure. The retorting procedu the same as described in 3.532. A drop of demulsi agent is added to the liquid receiving tube to pr emulsion formation with the mercury.

5.52 PENTANE EXTRACTION METHOD

5.521 Apparatus

Normal laboratory equipment is suitable for ing the sample and extracting the oil by decant Special glass separator bulbs with a total volu approximately 100 cc, but with a small, gra bottom section, are necessary for accurate me ment of the residual oil. A constant-temperatu is required for the evaporation of the pentan

5.52F1 presents an example of a suitable equipment arrangement. A volumetric mercury pump is used to determine sample bulk volume and gas content.

5.522 Procedure

The sample, as received, is divided into two parts, one for extraction and permeability measurement and the other for measurement of porosity and fluid saturations. The bulk volume of the unextracted sample is obtained by displacement in a volumetric mercury pump. The volume of the pore occupied by gas is then determined by the volume of mercury injected at a pressure of about 750 psi to 1,000 psi, as described in 3.533. The sample is removed from the mercury pump, then crushed in a beaker with a small amount of pentane. The pentane is decanted into a separator bulb, and fresh pentane is added to the crushed sample. A total of 50 to 100 cc of pentane is usually sufficient to completely extract the oil. The separator tube is then placed in a constant-temperature bath at 160 F. where the pentane is boiled off. (A straw or similar substance is placed in the tube to facilitate bubble formation and to permit agitation.) The recovered-oil volume is read when no further boiling is observed upon agitation. A lower bath temperature, e.g., 120 F., is desirable when working with high-gravity crudes or distillates.

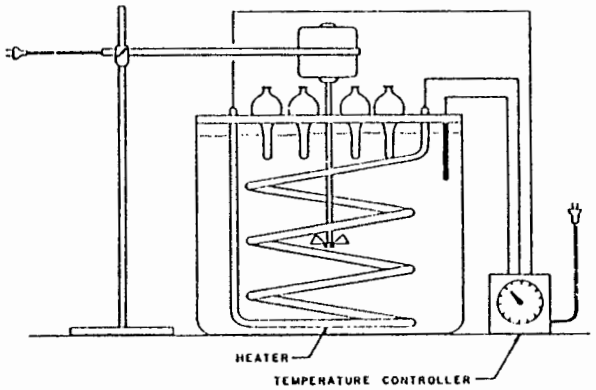


FIG. 5.52F1 — PENTANE EVAPORATION APPARATUS

5.523 Calculations

The volume of recovered oil is corrected for excessive losses with the pentane, or for failure to remove all of the pentane by comparison with calibration curves, as shown in Fig. 5.52F2. The water content is then calculated as a percentage of the bulk volume of the sample by a material-balance equation:

$$\rho n = (1 - \phi)\rho_{sd} + V_{bg} \cdot \rho_g + V_{bw} \cdot \rho_w + V_{bo} \cdot \rho_o \quad (24)$$

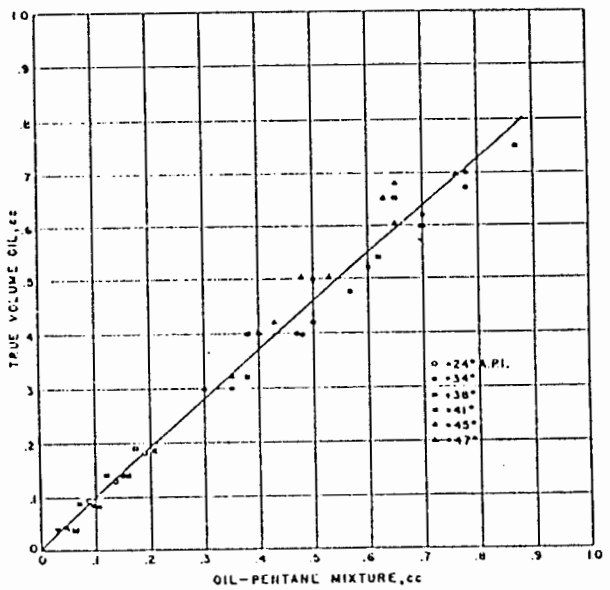


FIG. 5.52F2—PENTANE EVAPORATION DATA WATER-BATH TEMPERATURE, 160 F.

Wherein:

ρn = natural density of the fresh sample.
ϕ = porosity as a fraction of bulk volume.
V_{bg} = gas content as a fraction of bulk volume.
V_{bw} = water content as a fraction of bulk volume.
V_{bo} = oil content as a fraction of bulk volume.
ρ_{sd} = sand grain density.
ρ_g = density, gas.
ρ_w = density, water.
ρ_o = density, oil.

Equation 24 may be rearranged in the form:

$$V_{bw} = [\rho_{sd} - \rho_n - V_{bo}(\rho_{sd} - 0.8) - V_{bg} \cdot \rho_{sd}] / (\rho_{sd} - 1) \quad (25)$$

Wherein: 0.8 is taken as the average density of crude oil in the pore spaces and the density of the gas is negligible in comparison with the sand grain density.

The values for V_{bo}, V_{bg}, and ρ_n are measured. The value for ρ_{sd} is either determined experimentally or assumed for a formation where average data are available.

6.0 SUPPLEMENTARY TESTS

The gravity of oil and the salinity of water in core samples are supplementary data often obtained routinely during core analysis. Accordingly, these two tests have been included as the data obtained from them is an aid to interpreting other routine core-analysis data.

6.1 OIL GRAVITY

The specific gravity of the oil must be known in order to convert oil weight to oil volume in the distillation-extraction method for determining fluid saturations (3.55). In the use of the retort method for fluid-saturation measurements, the retorts must be calibrated with crude oils of various gravities (see 3.53 and Fig. 3.53F4). If the gravity of the oil recovered from the retort during the calibration procedure is measured, the gravity change effected by the heating process is obtained. This gravity change

varies with the type of oil and geographic source, and the retorts should be calibrated accordingly. If the gravity of the oil recovered from a core sample during a fluid-saturation measurement is determined and the proper gravity-change factor is used, then the gravity of the oil in the core prior to analysis can be estimated.

The oil gravity may be determined by a drop method or a weight method. The drop method consists of suspending a drop of the oil in a liquid medium, the gravity of which can be measured with a hydrometer or a specific-gravity balance. The weight method involves weighing a small amount of the oil in a calibrated pycnometer. The gravity is obtained by dividing the weight of the oil by the pycnometer volume.

6.11 OIL-DROP METHOD

6.111 Apparatus

a. Glass or clear-plastic cylinder.
b. API hydrometers or specific-gravity balance.

6.112 Procedure

A drop of the oil recovered from the core during the fluid-saturation test is placed in a glass or plastic cylinder containing a solution of methyl alcohol and water. The gravity of this solution is subsequently adjusted by the addition of alcohol or water until the oil drop remains suspended; i.e., after gentle agitation of the mixture, the drop neither rises nor falls. The gravity of the solution is then measured with an API hydrometer or a specific-gravity balance. The correct procedure for measuring gravity with a hydrometer is found in *ASTM D 287-55: Method of Test for API Gravity of Petroleum.*[14] The observed API gravity at the test temperature is corrected to the gravity of 60 F. and converted to specific gravity by the use of Tables 5 and 3, respectively, of the *ASTM-IP Petroleum Measurement Tables* (American Edition).[15] A specific-gravity balance permits a direct reading of gravity. A simple chart for converting units of liquid gravity and density may be useful.[16]

6.113 Precautions

a. Any air bubbles adhering to the surface of the oil drop must be removed before adjusting the gravity of the alcohol-water solution.

b. The solution must be gently agitated after each addition of alcohol or water to insure a uniform solution and gravity.

6.114 Advantage

a. Elaborate equipment is not required.

6.115 Limitation

a. Adjustment of alcohol-water ratio is time-consuming.

6.12 WEIGHT METHOD

6.121 Apparatus

a. Balance with accuracy of 0.001 gram.
b. Calibrated pycnometers.

The pycnometers can be made of thin-wall capillary tubing formed in a U-shape. Various sizes can be prepared by varying the length and/or the inside diameter of the tubing. The volumes are calibrated with a liquid of known density (CO_2-free distilled water may be used) with the pycnometer completel full or filled to an etched reference line.

6.122 Procedure

A portion of the oil recovered from the core by th fluid-saturation test is drawn into the pycnometer. is preferable that the largest practical amount sample be utilized for the gravity determination. Tl pycnometer containing the oil is weighed on analytical balance. The difference between this tot oil sample. The gravity is obtained by dividing tl weight and the previously determined weight of t pycnometer represents the weight of the oil samp The gravity is obtained by dividing the weight of t oil by the calibrated volume of the pycnometer.

6.123 Precaution

The pycnometer weight should be held to a mi mum. This will reduce errors by allowing the weig of the oil to be a significant amount of the to weight.

6.124 Advantages

a. Extremely accurate readings may be obtai if the pycnometer has been properly calibrated.
d. Determination is made in a short time.

6.2 CORE-WATER SALINITY DETERMINATION

A salinity determination on water present in the core is often desirable as it may aid in core-analysis data interpretation and in electric-log evaluation. Salinity is usually defined as the amount of chloride ion present in the core water expressed as sodium chloride. However, if the salinity is calculated from a resistivity measurement, it represents the contribution from all soluble electrolyte ions, converted to equivalent sodium chloride concentration. Measurements of the core water salinity are based on the assumption that all the soluble electrolytes in the core are contained in the formation water.

If the salinity of the formation water is known, the degree of flushing by the coring fluid may be indicated by the core-water salinity. If the formation-water salinity is unknown, a core-water salinity determination made on low-permeability cores—which are normally less affected by flushing—may approximate the formation-water salinity. At least it represents a lower limit for the salinity of the formation water. The formation-water salinity remains relatively constant within a given reservoir in many areas.

6.21 PREPARATION OF THE SAMPLE AND EXTRACTION OF THE SALT

Approximately 20 grams of sample are selec The sample may be a portion of that used in prev saturation tests or it may be selected from the at a point as close as possible to the saturation sam If the water saturation is not known, it shoul measured. The sample, which should be free of taminants—i.e., coring fluid or other foreign fl is ground in a mortar to approximately 16-mesh and dried in an oven for a period of 1 to 2 h (3.13). After cooling in a desiccator, the samp weighed and transferred to a flask. 100 ml of dist water are added and the mixture is stirred vigor for several minutes. Agitation is continued pe ically for a minimum of 1 hour. The resulting solution is filtered or decanted and the chloride tent of the water is determined, using either *a*, c ical titration, or *b*, resistivity measurement. salinity is expressed as parts of sodium chlorid million parts of core water, although other salt usually present.

6.22 CHEMICAL TITRATION METHOD

6.221 Principle

The filtrate obtained by separation of the crushed sample and the water used in the leaching process is titrated with a standardized silver nitrate solution, using potassium chromate as an indicator. The salinity of the water is expressed as parts per million sodium chloride in the core water.

6.222 Advantages

a. Rapid and convenient method.
b. Chloride determination is accurate.

6.223 Limitations

a. Result is expressed as sodium chloride. Ions other than chlorides present in the solution are not detected.
b. The apparent core-water salinity will be too high if the core contains crystalline salt, which is found in some limestones and dolomites and, to a lesser degree, in some shales.

6.224 Apparatus and Procedure

The apparatus, reagents, and procedure for titration are described in detail in *ASTM D 512-55T: Methods of Test for Chloride Ion in Industrial Water.*[17] Reference should be made to Referee Method B. The calculation described in this reference will give the salinity in terms of chloride ion instead of sodium chloride. The calculation as sodium chloride is described in 6.24.

6.23 RESISTIVITY MEASUREMENT

6.231 Principle

The total ionic constituents of water may be estimated by measuring the resistivity. The resistivity varies, in an inverse manner, with the ionic concentration of sodium chloride and other salts. Standard graphs, which show the resistivity value for various salinities and temperatures of sodium chloride solutions, can be prepared from data in the literature (Fig. 6.24F1). If the resistivity is known, then the salinity of the core water, expressed as parts per million of sodium chloride, can be determined from such a graph, using a measured resistivity value.

6.232 Advantages

a. Rapid determination.
b. The resistivity data correlate with electric log measurements.
c. Measures total ionic concentration.

6.233 Limitations

a. Resistivity meter and cell must be calibrated.
b. Resistivity value must be corrected to a standard temperature.
c. All ions present in the water are calculated as sodium chloride.
d. The apparent core-water salinity will be greater if the core contains crystalline salt, which is found in some limestones and dolomites and, to a lesser degree, in some shales.

6.234 Apparatus

a. Resistivity cell.
b. Resistivity meter.

6.235 Procedure

The instrumentation should be calibrated with sodium chloride solutions so the measurements check the graphs shown in Fig. 6.24F1. A portion of the solution obtained by leaching the core is placed in the resistivity cell. The resistivity is measured on a suitable meter and calculated in ohm-meters. With the use of a standard graph (Fig. 6.24F1) and suitable calculations (6.24), the resistivity value is converted to a salinity value for the pore water.

Additional details on apparatus and procedure may be found in *ASTM D 1125-50T: Method of Test for Electrical Conductivity for Industrial Water.*[18]

6.24 CALCULATIONS

The measurements from the titration and resistivity methods are calculated to milligrams of sodium chloride leached from the sample. This represents the total salt from the pore water of the sample. The total salt and the amount of pore water obtained by saturation tests are used to calculate the concentration of salt in the pore water and this value is expressed in parts per million of sodium chloride.

a. The normality of the salt solution is calculated from the titration values by the formula:

$$N_1 = ml_2 N_2 / ml_1 \qquad (26)$$

Wherein:

N_1 = normality of salt solution titrated.
ml_1 = volume of salt solution titrated.
N_2 = normality of silver nitrate.
ml_2 = volume of silver nitrate used.

The milligrams of sodium chloride leached from the core sample are calculated as follows:

$$N_1 \times 58.5 \times V = \text{total NaCl, mg} \qquad (27)$$

Wherein:

V = volume of water, in milliliters, used to leach or extract the sample (6.21).

b. The resistivity value for the salt solution can be converted directly to milligrams of salt from the sample using the conversion chart, Fig. 6.24F1.

c. The volume of the pore water can be obtained directly by difference between the weight of the sample before and after drying if no oil is present. The drying should follow the directions in 3.13.

If the sample contains oil, the fluid saturations (3.2) and the porosity (3.3) must be determined either on this sample or an adjacent piece. The amount of water contained in the sample can be calculated as follows:

$$[(W/D)/(1 - \phi)] = V_b \qquad (28)$$

$$(V_b)\ (\phi)\ (S_w) = \text{core water, ml} \qquad (29)$$

Wherein:

W = dry weight of sample.
D = grain density.
ϕ = porosity, as fraction.
V_b = bulk volume of sample.
S_w = water saturation, as fraction.

If the grain density has not been determined, use representative value for the formations of interest. The density of water is taken as 1 gram per ml.

d. The salinity of the pore water is obtained by:

$$\frac{\text{mg NaCl (6.24a. or b.)}}{\text{ml pore water (6.24c.)}} \times 100 = \text{mg NaCl/100 g pore water} \qquad (30)$$

This value is converted to parts per million using the chart in Fig. 6.24F1.

This chart is designed to be used with the assumptions in 6.2 for core analysis. Values for milligrams per liter obtained by water geo-analysis do not correspond to parts per million in very saline solutions. Thus, the values for milligrams per liter from geo-analysis must be divided by the density of the solution being analyzed to convert to parts per million on this chart.

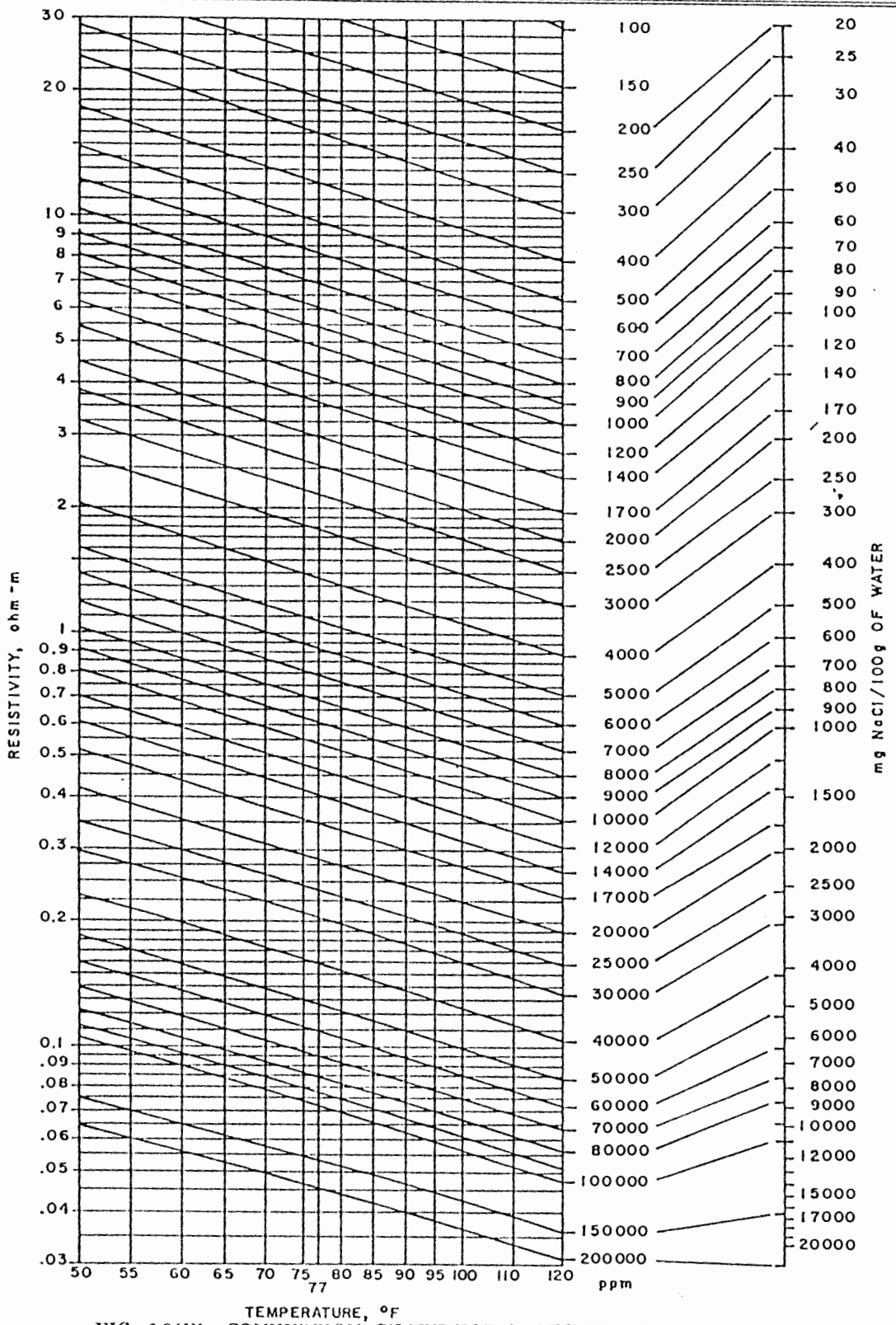


FIG. 6.24F1—CONVERSION CHART FOR SALINITY DETERMINATION
(Data From Critical Tables)

6.25 PRECAUTIONS

6.251 Chemical Titration Method

a. Make blank chloride determination to correct for any chloride present in the glassware and water used in the tests.

b. Standardize silver nitrate solution frequently using a standardized sodium chloride solution.

c. Store silver nitrate solution in brown bottles away from light.

d. An adequate volume of solution must be used so the silver ion used by indicator is negligible compared to the total amount titrated.

e. Proper concentration of indicator should be used.

6.252 Resistivity Method

a. Be certain that electrodes of the resistivity cell are clean before making a measurement.

b. Check resistivity meter frequently.

c. Check electrode for cell constant over entire range of use.

d. Correct readings for temperature.

7.0 REPORTING

The major value of the testing program can be lost by inadequate reporting. Core-analysis data are reported in written and graphical form depending upon the type of tests performed and the projected use of the data. These reports become permanent records of the observations made at the time of testing. Furthermore, the value of accurate data for use in reservoir engineering, etc. cannot be over-emphasized. The potential desire to trade or purchase data among operators can place as great a premium on reliable records as any immediate use. Therefore, the more completely and accurately this record is prepared the more valuable it will be at a later time.

7.1 WRITTEN REPORT

The written report should include all of the data, positively identified and tabulated in some convenient form. Identification should include such items as depth, well, geographic location, etc. The exact presentation of the data may be determined between the user and the tester. Reference should be made to the original testing request to provide continuity in the records.

Unusual circumstances should be noted, e.g., core condition, behavior during testing, and anomalies in the data. Any commentary which may assist the interpretation of the data, at present or in the future, should be recorded. The methods used to obtain the core data should be identified. Any deviation from the procedures in the recommended practice should be noted.

7.2 GRAPHICAL REPORT

It is suggested that any standardization of the graphical report forms correspond either to *API RP 31* and *RP 33* for the electrical and nuclear logs, or *RP 34* for hydrocarbon mud logs.

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BIOVENTING INITIATIVE WORK PLAN

SITES SD-47 AND FT-31

VOLUME III - SITE SAFETY AND HEALTH PLAN

March 1995

49 CES/CEV
Holloman Air Force Base,
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BIOVENTING INITIATIVE WORK PLAN
SITES SD-47 AND FT-31
HOLLOMAN AIR FORCE BASE, NEW MEXICO

VOLUME III - SITE SAFETY AND HEALTH PLAN

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Terc/biovent2.rev

SITE SAFETY AND HEALTH PLAN APPROVAL

This Site Safety and Health Plan (SSHP) was developed to outline health and safety guidelines and procedures for the Bioventing Pilot Study under Delivery Order (DO) No. 1, Work Authorization Directive (WAD) No. 7 at Holloman Air Force Base (AFB), New Mexico. The signatures below indicated concurrence with the procedures specified in the plan and a commitment to the philosophy of quality to all project personnel.

William L. Hughes, Lead Geologist, Groundwater Technology Government Services, Inc.

Signature_____ Date_____

Sara C. Brothers, Project Manager, Groundwater Technology Government Services, Inc.

Signature_____ Date_____

Stephen J. Venuti, Certified Industrial Hygienist, Groundwater Technology Government Services, Inc.

Signature_____ Date_____

Diane Morrell, Certified Industrial Hygienist, Foster Wheeler Environmental Corporation

Signature_____ Date_____

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LIST OF ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AFB	Air Force Base
ANSI	American National Standards Institute
BTEX	Benzene, Toluene, Ethylbenzene, Xylenes
CFR	Code of Federal Regulations
CGI	Combustible Gas Indicator
CIH	Certified Industrial Hygienist
CPR	Cardiopulmonary Resuscitation
CRZ	Contamination Reduction Zone
CSP	Certified Safety Professional
CET	Certified Environmental Trainer
CIH	Certified Industrial Hygienist
COHN	Certified Occupational Health Nurse
DO	Delivery Order
DOT	Department of Transportation
EMS	Emergency Medial Services
EPA	Environmental Protection Agency
eV	Electron Volts
FID	Flame Ionization Detector
GFCI	Ground-Fault Circuit Interrupter
HBV	Hebatitis B Virus
HEPA	High Efficiency Particulate Air-Purifying
H&S	Health and Safety
HSM	Health Safety Manager
IDLH	Immediately Dangerous to Life or Health
IP	Ionization Potential
JSA	Job Safety Analysis
LEL	Lower Explosive Limit
MD	Medical Doctor
MSDS	Material Safety Data Sheet

LIST OF ACRONYMS (Continued)

NBR	Nitrile Butyl Rubber
NIOSH	National Institute for Occupational Safety and Health
NMED	New Mexico Environmental Department
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PID	Photoionization Detector
PIR	Preliminary Incident Report
PM	Project Manager
POC	Point of Contact
ppb	parts per billion
PPE	Personal Protection Equipment
ppm	parts per million
RR	Relative Response
SHSO	Site Health and Safety Officer
SSHP	Site Safety and Health Plan
SOSP	Standard Operating Safety Procedures
STEL	Sgort-Term Exposure Limit
SWMU	Solid Waste Management Unit
TAL	Target Analyte List
TBA	To Be Announced
TERC	Total Environmental Restoration Contract
TLV	Threshold Limit Value
TM	Task Manager
TPH	Total Petroleum Hydrocarbon
TWA	8-hour Time Weighted Average
USACE	United States Army Corps of Engineers
UST	Underground Storage Tank
VOC	Volatile Organic Compound
VP (mmHg)	Vapor Pressure in Millimeters at Mercury at 68°F
WAD	Work Authorization Directive

1.0 INTRODUCTION

1.1 Site Safety and Health Plan Purpose

Groundwater Technology Government Services, Inc. (Groundwater Technology) has been retained by Foster Wheeler Environmental Corporation (Foster Wheeler) (MOA No. DENS-94-1159JM) to perform environmental services for the United States Army Corps of Engineers (USACE), Omaha District, Total Environmental Restoration Contract (TERC), Contract Number DACW45-94-D0003, DO No. 1, WAD No. 7.

The purpose of this SSHP is to provide Groundwater Technology field personnel, subcontractors and other visitors with an understanding of the potential chemical, physical and related hazards that exist or may arise while the tasks of this project are being performed.

1.1.1 Overview of Project Scope, Hazards and Levels-of-Protection

SCOPE:	Soil gas survey, drilling and system installation, and bioventing test.
HAZARD SUMMARY: • Chemical • Physical • Biological • Other (Radiological, etc.)	 Low (petroleum hydrocarbons) Moderate Not anticipated Not anticipated
LEVEL(s)-OF-PROTECTION:	Level D/Level C Upgrade Contingency
CLIENT OR OWNER:	United States Army Corps of Engineers, Omaha District
SITE NAME:	SD-47 and FT-31 - Holloman AFB
SITE ADDRESS:	Holloman Air Force Base, New Mexico
PROJECT NUMBER:	830012201.07
PROJECT MANAGER:	Sara C. Brothers
DATE(S) OF SITE WORK:	March 1995 through October 1995 (0730-1630, Monday through Friday)
SITE SIZE:	Two sites within approximately 4 square miles.
SITE TOPOGRAPHY:	Relatively flat lying
SITE WEATHER:	Mostly sunny, temperature in high 50s (Spring) to high 90s (Summer).
SITE DESCRIPTION/HISTORY:	Holloman AFB is located in south-central New Mexico, approximately 5 miles southwest of the city of Alamogordo. Groundwater Technology has been contracted to conduct bioventing tests at two sites.

1.2 Document Hierarchy/Regulatory Basis

This SSHP is prepared in accordance with Occupational Safety and Health Administration (OSHA) 29 Code of Federal Regulations (CFR) 1910.120 and the USACE Safety and

Health Requirements Manual EM 385-1-1, and is designed to be consistent with Groundwater Technology's Corporate Health & Safety Program and Foster Wheeler's Site Specific/Corporate Health and Safety Program. This SSHP describes the procedures to be followed in order to reduce employee exposure to potential health hazards which may be present at the project site. The emergency response procedures necessary to respond to such hazards are also described within this SSHP.

1.3 Site Location, History and Description

A summary of the WAD and description of each of the sites is presented in this section. A more detailed description of the sites is presented in the work plan.

1.3.1 Site FT-31 Fire Department Training Area

This site is an old training area which includes an oil/water separator which was installed in 1980 and tank within a drainage pit. Contamination has been characterized as JP-4. The entire site is enclosed by a fence and occupies approximately 5,000 square feet. Waste oils, solvents and fuels were delivered to the Fire Protection training area. Flammable liquids were sprayed and ignited on mock aircraft. Since 1979 only new fuel has been used.

1.3.2 Site SD-47 POL Washrack Area

Petroleum hydrocarbon contamination resulted from washwater flowing from a washrack to a nearby drainage ditch. Contamination has been characterized as waste JP-4. Total Petroleum Hydrocarbon (TPH) contamination still exists in an area approximately 30 feet by 60 feet by 8 feet deep.

1.4 Scope of Work

WAD No. 7 of Delivery Order No. 1 consists of conducting a soil gas survey, the installation of a pilot system and conducting a bioventing pilot test for a period of 6 months at two sites at Holloman AFB, New Mexico.

The objective of the WAD is to conduct *in situ* respirometry and air permeability tests that will determine the appropriateness of bioventing as a remedial alternative at two sites at Holloman AFB, New Mexico. The WAD includes a soil gas survey to identify bioventing well locations, the installation of a pilot system and a bioventing pilot test which will take place for a period not to exceed six months. Previous preliminary assessment/site investigations indicate that the groundwater has been impacted by petroleum hydrocarbons and solvents.

Contractor personnel will perform initial system installation and startup activities, and continued monthly operation and maintenance throughout the life of this project. Trained Base personnel will perform weekly site checks to ensure uninterrupted system operation.

All personnel who perform on-site activities specified in the Field Operation Plan (Volume I) shall comply with all requirements of the SSHP, including a medical surveillance program.

2.0 ORGANIZATION/KEY PERSONNEL and RESPONSIBILITIES

2.1 Project Team

- On-site Personnel:

Name	Project Title/Assigned Role	Phone Numbers
Chuck Schick	Site Manager *{required}*	work: (505) 242-3113 home: (505) 836-7882
TBA	Task Supervisor(s) *{optional}*	work: home:
Chuck Schick	Site Health and Safety Supervisor *{required}*	work: (505) 242-3113 home: (505) 836-7882
TBA	Competent Person *{requirement depends upon site}*	work: home:
Chuck Schick	First Aid Personnel *{required}*	work: (505) 242-3113 home: (550) 836-7882

- Other Project Personnel:

Name	Project Title/Assigned Role	Phone Numbers
Sara Brothers	Project Manager (PM)	work:(505) 242-3113 home:(505) 345-3252
Nathan Grant	Health and Safety Representative	work:(602) 966-0808 home:(602) 350-9213
Stephen Venuti	Groundwater Technology Health and Safety Manager	work: (617) 769 7600 ext. 358 home: (617) 665 8603

2.1.1 Roles and Responsibilities

The primary objective of this SSHP is the well-being of all field personnel and the community surrounding this site. In order to accomplish this, project staff and approved subcontractors shall acknowledge and adhere to the policies and procedures established herein. The control of site hazards is dependent upon the degree to which management enforces compliance and employees cooperate with the specified health and safety requirements.

Therefore, personnel at all levels of the organization must recognize their individual responsibility to comply. All activities covered by this SSHP must be conducted in compliance with this SSHP and with applicable federal, state and local health and safety regulations, including 29 CFR 1910.120 and EM 385-1-1. Personnel covered by this SSHP who cannot or will not comply must be excluded from site activities.

Accordingly, all personnel assigned to this project shall be made aware of the contents of this SSHP and sign the Agreement and Acknowledgement Statement (Appendix A-1) to certify that they are aware and understand the contents, and agree to abide by its provisions. Any changes in the scope of work of this project and/or site conditions must be amended in writing on the SSHP Amendment Sheet (Appendix A-2) and approved by the Groundwater Technology and Foster Wheeler Health and Safety Manager/Certified Industrial Hygienists (CIH).

Any person not actively participating in the work at the site is regarded as a "visitor" and must follow Groundwater Technology's visitor/trainees guidelines (Appendix A-3).

- **Project Manager:** Responsible for managing the project (i.e. coordination, scheduling, notifications, correspondence, and reporting). The project manager will ensure that the SSHP is followed and that the project is completed and as contracted.

- **Site Managers and Task Supervisors:** Responsibility for compliance with company Health and Safety programs, policies, procedures and applicable laws and regulations is shared by all Groundwater Technology management and supervisory personnel. This includes the need for effective oversight and supervision of project staff necessary to control the health and safety aspects of daily operations.

- **Site Health and Safety Officer/Supervisor (SHSO):** SHSO are appointed on a per-project basis by the Project Manager and/or other management representatives. The SHSO is defined by OSHA 1910.120 as "...the individual located on a hazardous waste site who is responsible to the employer and has the authority and knowledge necessary to implement the site safety and health plan and verify compliance with applicable safety and health requirements." The SHSO is responsible to both project management and the designated local/regional health and safety representative with regard to the completion of these assigned duties.

- **Competent Person:** A "Competent Person", as defined by OSHA 1926.20(b) - Accident Prevention Responsibilities, is the individual "who is capable of identifying existing and predictable hazards in surroundings or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them." The competent person may have other duties such as the SHSO. A competent person must be designated on a site-by-site basis based on the site conditions, scope-of-work, and the individual's ability to recognize site-specific hazards and take appropriate corrective actions.

- **First Aid Personnel:** Individual(s) designated by Groundwater Technology having current (Red Cross or equivalent) training and certification in basic first aid and cardiopulmonary resuscitation (CPR). This person must also have received training and information regarding Groundwater Technology's bloodborne pathogen control program including the required use of "universal precautions" and the availability of Hepatitis B Virus (HBV) vaccinations.

- **Staff**: Ultimate control of health safety is in the hands of each individual employee. Therefore, each employee must become familiar with and comply with all health and safety requirements associated with their position and daily operations. Employees also have the responsibility to notify the appropriate management and/or health and safety representative of unsafe conditions and accidents/injuries immediately. When employees are issued respirators or any other personal protective equipment (PPE), they are responsible for ensuring that said items are used properly, cleaned as required and maintained in good working order.

- **Subcontractors**: This SSHP is intended to incorporate subcontractor-specific tasks. All Groundwater Technology of Foster Wheeler subcontractors are required to review and indicate by signature that they will abide by the SSHP. Individual tasks will be reviewed with subcontract personnel during daily "tail gate" safety meetings. If necessary the SHSO will prepare a field addendum to address task specific deficiencies/changes.

The activities described in this SSHP may be subject to audit by the Groundwater Technology or Foster Wheeler Health and Safety Manager. The appropriate schedule for any such audit will be determined at a later date.

In addition to the possible need for a formal audit, daily safety and health inspections shall be conducted and recorded as part of the daily site log by the SHSO to determine if operations are being performed in accordance with the SSHP, applicable OSHA regulations and contract requirements.

Groundwater Technology personnel have the authority to stop work performed by our sub-contractors at this site if work is not being performed in accordance with the requirements of this SSHP.

Complete a Preliminary Incident Report (Appendix A-4) if this occurs.

3.0 HAZARD ANALYSIS

3.1 Hazard Identification

Groundwater Technology follows along a traditional approach to worker health and safety by using job safety analysis (JSA) as a technique to identify hazards associated with certain job tasks. This technique is prepared in a fashion to meet requirements described in the job hazard analysis per the USACE Safety and Health Requirements Manual EM-385-1-1 (October 1992).

Appendix C-1 contains JSA sheets for potential hazards expected to be encountered while engaging in site specific tasks for this project. The SHSO will inspect the site to ensure that all of the tasks conducted at the site are performed according to the JSAs. Additional JSA sheets can be added in the future as an amendment to this document to address any unexpected or unforeseeable hazards not yet identified in the USACE Manual EM-385-1-1, the Groundwater Technology Health and Safety Policy and Procedure Manual, or the described JSAs. The minimum required PPE is Level D, however, upgrades may be necessary based on air monitoring (Table 7-2). The maximum anticipated chemical of concern concentrations in groundwater are presented in Table 3-1. The SSHP will also be periodically reviewed by the Project Manager, SHSO and/or the CIH to determine if changes in the SSHP are needed. If any of these changes are due to change in the scope of work of this project and/or site conditions, the SSHP will be amended in writing on the SSHP Amendment Sheet (Appendix A-2) and approved by the CIH.

3.2 Hazard Assessments

The following hazard assessment applies only to the activities within the specified scope of this SSHP.

3.3 Chemical Hazards

TABLE 3-1 CONTAMINANT PROFILES		
Chemical	**Exposure Route**	**Symptoms of Overexposure**
JP-4/ Petroleum Hydrocarbons/ BTEX	Inhalation, Ingestion	Staggering gait, slurred speech, mental confusion.

3.3.1 JP-4 as Total Volatile Organic/BTEX Compounds

Exposure to the vapors of **benzene, ethyl benzene, toluene** and **xylenes** (BTEX) above their respective permissible exposure limit (PEL), as defined by OSHA, may produce irritation of the mucous membranes of the upper respiratory tract, nose and mouth. Overexposure may also result in the depression of the central nervous system. Symptoms of such exposure include drowsiness, headache, fatigue and drunken-like behavior. Benzene has been determined to be carcinogenic, targeting blood-forming organs and bone marrow.

The vapor pressures of these compounds are high enough to generate significant quantities of airborne vapor. On sites where high concentrations of these compounds are present, this can result in a potential inhalation hazard to the field team during subsurface investigations. However, if the site is open and the anticipated quantities of BTEX contamination are small (i.e. part per million [ppm] concentrations in the soil or groundwater), overexposure potential will also be small.

3.3.2 Chemicals Subject to OSHA Hazard Communication

All chemicals brought on site such as solvents, reagents, decontamination solutions, or any other hazardous chemical must be accompanied by the required labels, Material Safety Data Sheets (MSDS), and employee training documentation (OSHA 1910.1200). For additional information refer to the **Groundwater Technology Hazard Communication Program**, provided in Appendix B-1. A log to record hazardous chemicals brought on site is provided in Appendix B-2. MSDS definitions are provided in Appendix B-3.

3.4 Physical Hazards

A "Competent Person" must perform frequent and regular inspection of the site, materials and equipment in accordance with 1926.20 to identify site hazards. All personnel on site should be provided with the information and training necessary to avoid accidental injury. This includes assuring that the site is maintained in a such a way that slip, trip and fall hazards are recognized and eliminated or controlled. Basic personal protective equipment (steel-toed boots, hardhats and safety eyewear) must be available and its use enforced.

3.4.1 Mechanical Equipment/Construction Hazards

The use of drill rigs, Geo-Probes, trucks and other mechanical equipment represent potentially serious construction hazards. Whenever such equipment is used, personnel in the vicinity should be limited to those who must be there to complete their assigned duties. All personnel must avoid standing within the turning radius of the equipment or below any suspended load. Job sites must be kept as clean, orderly and sanitary as possible. When water is used, care must be taken to avoid creating muddy or slippery conditions. If slippery conditions are unavoidable, barriers and warning signs must be used to warn of these dangers.

Personnel should not turn their backs to operating machinery. No loose clothing, jewelry, hair or other personal items should be worn around rotating equipment or other equipment

that could catch or ensnare these items. Always stand far enough away from operating machinery to prevent accidental contact which may result from mechanical or human error.

3.4.2 Electrical

OSHA regulations require that employees who may be exposed to electrical equipment be trained to recognize the associated hazards and the appropriate control methods. All **extension cords** used for portable tools or other equipment must be designed for hard or extra usage and be (three wire) grounded.

All 120-volt, single-phase 15- and 20-ampere receptacle outlets on construction sites and other locations where moisture/water contact may occur must be equipped with **ground-fault circuit interrupters (GFCI)** units. GFCI units must be attached directly to or as close as possible to the receptacle. GFCI located away from the receptacle will not protect any wiring between the receptacle and the GFCI unit. Only the wiring plugged into the GFCI and outward will be protected by the GFCI.

All **(temporary lighting)** lamps for general illumination must be protected from accidental breakage. Metal case sockets must be grounded. Portable lighting in wet or conductive locations should be 12 volts or less.

3.4.3 Fire and Explosion

The possibility of flammable materials being encountered during field activities must be recognized and the appropriate steps necessary to minimize fire and explosion must be observed. This includes situations where **excessive organic vapors or free product** are encountered. When this occurs, monitoring with a combustible gas indicator (CGI) is required.

Excessive organic vapors, for the purposes of initiating the use of a CGI, are defined as sustained readings (i.e., continuous for at least five minutes) at or above 100 units or as an instantaneous reading at or above 1,000 units on the photoionization detector (PID) or

flame ionization detector (FID), in close proximity (within 1 foot or less) of the borehole, test pit, sampling location or other area of potential exposure.

Control methods may include forced ventilation and/or filling the borehole with enough water to inhibit the release of methane and other gases which would otherwise escape through the top of the borehole.

- If forced (mechanical) ventilation is to be used, all such equipment must be approved for Class I, Division I hazardous atmospheres. The blower must be positioned to blow across the top of the borehole so that gases and vapors may be diluted as they exit the borehole. Do not attempt to suck out the gases or vapors. Blowers, all other mechanical equipment, and tools which could release sparks or static electricity must be bonded and grounded.

- Regardless of the gas/vapor control method used, the atmosphere surrounding the borehole must be frequently monitored using direct reading instruments approved for Class I, Division I hazardous atmospheres. Monitoring should be conducted within 1 to 2 feet of the top of the borehole. Do not insert sampling devices into the borehole. Never approach the auger or drill shaft while it is in operation.

- If combustible gas levels equal or exceed 10 percent of the lower explosive limit (LEL), when monitored as described above, operations should be immediately shut down and the area evacuated until appropriate control measures have been implemented and levels have been resampled and verified safe for reentry.

- Regardless of actual instrument readings, if all sources of ignition can not be controlled, operations should be immediately shut down and the area evacuated until ignition sources have been eliminated. Ignition sources include, but are not limited to: smoking, static electricity, lighting, open flames, spontaneously ignitable substances, frictional heat or sparks, hot surfaces, radiant heat, electrical sparks, stray currents, cutting and welding, and ovens, furnaces and heating equipment.

  In situations where hexane, methanol or other flammable solvents are needed for field activities, the following precautions must be observed: **Keep flammable and combustible materials away from heat, sparks and open flames. Do not smoke around flammable or combustible materials. Keep all flammable and combustible liquids in approved and properly labelled safety containers.**

At least one 10-pound ABC fire extinguisher must be located within 100 feet of each work area.

3.4.4 Heat and Cold Stress

Overexposure to temperature extremes can represent significant risks to personnel if simple precautions are not observed. Typical control measures designed to prevent **heat stress** include dressing properly, drinking plenty of the right fluids, and establishing an appropriate work/break regimen. Typical control measures designed to prevent **cold stress** also include dressing properly, and establishing an appropriate work/break regimen. The project manager must assure that the appropriate measures are observed.

3.4.5 Moving Vehicles, Traffic Safety

All vehicular traffic routes which could impact worker safety must be identified and communicated. Whenever necessary, barriers or other methods must be established to prevent injury from moving vehicles. This is particularly important when field activities are conducted in parking lots, driveways, ramps or roadways. OSHA 1926.201 specifies that when signs, signals or barricades do not provide adequate protection from highway or street traffic, flagmen must be utilized. **Flagmen must wear red or orange garments. Garments worn at night must be reflective.**

3.4.6 Noise

Noise exposure can be affected by many factors including such as the number and types of noise sources (continuous vs. intermittent or impact), and the proximity to noise-intensifying structures such walls or building which cause noise to bounce back or echo. The most important factor affecting total noise exposure is distance from the source. The closer one is to the source, the louder the noise. Drill rigs, backhoes or other mechanical equipment can be sources of significant noise exposure. In order to reduce the exposure to this noise, personnel working in areas of excessive noise must use appropriate hearing protectors (ear plugs or ear muffs).

In general, wherever actual data from sound level meters or noise dosimeters is unavailable and it is necessary to raise one's voice above a normal conversational level to communicate with others within 3 to 5 feet away, hearing protection should be worn.

3.4.7 Overhead Utilities and Hazards

Overhead hazards can include low hanging structures which can cause injury due to bumping into them. Other overhead hazards include **falling objects, suspended loads, swinging loads and rotating equipment.** Hardhats must be worn by personnel in areas where these types of physical hazards may be encountered. Barriers or other methods must also be used to exclude personnel from these areas were appropriate. Electrical wires are another significant overhead hazard. According to OSHA (29 CFR 1926.550), **the minimum clearance which must be maintained from overhead electrical wires is 10 feet** from an electrical source rated $\leq$ 50 kV. Sources rated > 50 kV require a minimum clearance of 10 feet plus 0.4 inches per kV above 50 kV. OSHA's minimum clearance requirements are roughly equivalent to those specified by the Army Corp of Engineers (EM 385-1-1, Table 11-3) as summarized in Table 3-2.

TABLE 3-2
MINIMUM CLEARANCE REQUIREMENTS FROM OVERHEAD ELECTRICAL WIRES

Nominal Voltage (kV)	Minimum Clearance (ft)
0-50	10
51-100	12
101-200	15
201-300	20
301-500	25
501-750	35
751-1000	45

3.4.8 Pedestrian Traffic

The uncontrolled presence of pedestrians on a drilling or excavation site can be hazardous to both the pedestrian and site workers. Prior to the initiation of site activities, the site should be surveyed to determine if, when and where pedestrian may gain access. This includes walkways, parking lots, gates and doorways. Barriers or caution tape should be used to exclude all pedestrian traffic. **Exclusion of pedestrian traffic is intended to prevent injury to the pedestrians and eliminate distractions which could cause injury to site workers.**

3.4.9 Underground Utilities and Hazards

The identification of underground storage tanks (USTs), pipes, utilities and other underground hazards is critically important prior to all drilling, excavating and other intrusive activities. In accordance with OSHA 29 CFR 1926.650, **the estimated location of utility installations, such as sewer, telephone, electric, water lines and other underground installations that may reasonably be expected to be encountered during excavation work, must be determined** prior to opening an excavation. The same requirements apply to drilling operations and the use of soil gas probes. Where public utilities may exist, the utility agencies or operators must be contacted directly or through a utility-sponsored service such as **Digsafe**. Where other underground hazards may exist, reasonable attempts must be made to identify their locations as well. **Failure to identify underground hazards can lead to fire, explosion, flooding, electrocution or other life threatening accidents.**

3.5 Biological Hazards

Project personnel should be provided with the information and training necessary to avoid accidental injury or illness which can result from exposure to biological hazards. This includes assuring that the site is carefully assessed so that the hazards associated with poisonous plants, insects or other sources of biological contamination are recognized and eliminated or controlled.

3.5.1 Poisonous Plants

Although poisonous plants are not anticipated to be encountered at the site, personnel should be aware of the presence of poisonous plants in areas adjacent to the site. **Poison ivy** is a climbing plant with alternate green to red leaves (arranged in threes) and white berries. **Poison oak** is similar to poison ivy and sumac but its leaves are oak-like in form. The leaves of these poisonous plants produce an irritating oil which causes an intensely itching skin rash and characteristic blister-like lesions.

Cactus spines can inflict painful injuries to unwary site personnel. Visually survey each area of site where cacti may grow prior to walking across. Workers should be particularly alert to cacti which are low to the ground. Avoid stepping on or scraping up against cactus plants. Be aware that spines may not always be readily apparent to the casual observer.

3.5.2 Insects

Stinging insects, primarily **spiders, scorpions, bees** and **wasps**, are prevalent in the area of the sites during the warmer months. Avoid reaching into well vaults or other restricted areas without first ensuring that there are no insects or nests.

3.5.3 Rattlesnakes

Poisonous snakes (Rattlesnakes) could be encountered during site activities. Employees are advised to be alert to this danger. Snake bites can be painful and lead to serious illness if not treated immediately. If bitten employees must seek medical attention immediately. A snake bite kit should be included as part of the first aid kit. The best thing to do, however is to avoid contact. Wear sturdy leather boots. Avoid walking in areas where snakes may hide. Use extreme caution when moving or lifting objects which could be used by snakes as cover. Never reach under or behind such objects or into other areas where snakes may hide.

4.0 SITE CONTROL

4.1 Controlled Work Zones

Groundwater Technology observes the site control methods suggested in the "Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities," NIOSH/OSHA/USCG/EPA, November, 1985. Accordingly, the area surrounding each of the active work areas is to be divided into three zones: the exclusion or "Hot" zone, the contamination reduction zone (CRZ), and the support zone.

4.1.1 Exclusion Zone

Due to the scattered locations of the activities covered within the scope of this SSHP, the actual zones are expected to change frequently in accordance with daily activities. Therefore, all exclusion zones are expected to be temporary or dynamic. Site personnel will be advised of the locations of temporary work zones as part of the routine site safety meetings.

Each exclusion zone will consist of the active work areas where site investigations are taking place. A 15-foot radius will be established as the typical perimeter of the zone, however, this may be increased as necessary in order to protect unprotected personnel from contact with vapors, physical or other site related hazards that may arise from these operations. The perimeter of the zone will be marked with traffic cones and/or brightly colored hazard tape. Personnel entering these areas must wear the prescribed level of protective equipment.

4.1.2 Contamination Reduction Zone

Each CRZ will be a clearly marked corridor between the exclusion and support zones. The actual length and/or location of the corridor will also be temporary or dynamic in accordance with the locations of the exclusion zones. The CRZ is where personnel will begin the sequential decontamination process when exiting the exclusion zone. To prevent cross contamination and for accountability purposes, all personnel must enter and leave the

exclusion zone through the CRZ. A separate heavy equipment decontamination zone will be required.

4.1.3 Support Zone

The support zone will be an area outside the exclusion zone and CRZ where support trailers and equipment may be staged and support activities may be conducted. Eating, drinking and smoking will be allowed only in this area. Sanitary facilities, potable water and water and soap for hand washing along with containers for solid waste for use by Groundwater Technology subcontractor personnel should be located within this area.

4.1.4 Uncontrolled Areas

Portions of the site which are not designated as active exclusion, contamination reduction or support zones are considered to be uncontrolled areas within the context of this site safety and health plan and therefore not subject to the requirements of OSHA 1910.120.

4.2 Other Site Control Measures/Work Limitations

The following measures are designed to augment the specific health and safety guidelines provided in this plan.

- The "buddy system" will be used at by all field personnel. No one is to work alone in controlled/active work zones. The standby team member must be intimately familiar with the procedures for initiating an emergency response.
- Avoidance of contamination is of the utmost importance. Whenever possible, avoid contact with contaminated (or potentially contaminated) surfaces or materials. Walk around (not through) puddles and discolored surfaces. Do not kneel on the ground or set equipment on the ground. Protect air monitoring equipment from water by bagging.
- Hands and face must be thoroughly washed upon leaving the work area and before eating, drinking or any other activities.

- Eating, drinking, chewing gum or tobacco, smoking or any practice that increases the probability of hand-to-mouth transfer and ingestion of materials is prohibited except in the support zone after proper decontamination.
- Beards or other facial hair that interfere with respirator fit are prohibited for anyone who is required to wear a respirator.
- The use of alcohol or drugs is prohibited during the conduct of field operations.
- All equipment must be decontaminated or discarded, as designated by the SHSO, before leaving the site.

4.3 Site Preparation

Time and effort will be spent preparing the site/location prior to scheduled activities. Such preparation includes eliminating physical hazards (debris, weeds, ignition sources, etc.), identifying underground (steam, communications, electrical etc.) and overhead utilities, and construction/illumination.

Prior to drilling and/or other intrusive subsurface activities, a utility clearance (such as Digsafe, One Call, etc.) authorization number must be obtained. **Onbase activities will require a digging permit from the Civil Engineering Department.**

In addition, site/area maps are to be compiled, security measures established. Emergency services notified of activity, and a communications network set up.

4.4 Site Entry/Security

Site entry procedures are dictated by requirements for entry onto United States military installations and currently only authorized personnel are allowed access to the sites at Holloman AFB. Authorized personnel must meet all training and medical surveillance requirements stated in this SSHP and review and sign the agreement and acknowledgement sheet of the SSHP prior to being allowed access to the site.

Personnel authorized to perform work on this site include:

1. Sara Brothers, Project Manager
2. Stephen Venuti, C.I.H., Health and Safety Manager
3. TBA, SHSO
4. Dave Crowley, C.S.P., C.E.T., C.H.M.M.
5. TBA, On-Site Workers
6. Foster Wheeler Personnel
7. Regulatory Agency Personnel
8. USACE Personnel
9. Designated Holloman AFB Personnel

5.0 DECONTAMINATION

Proper decontamination is required of all personnel and equipment before leaving the site. All materials and equipment used for decontamination must be disposed of properly. Clothing, tools, buckets, brushes, and all other equipment that is contaminated must be secured in containers and labeled. Clothing not completely decontaminated on site should be secured in plastic bags before being removed from the site.

All water used in decontamination procedures shall be stored in 55-gallon drums until approval by the POC for disposal. Disposable sampling equipment and PPE will be placed in plastic bags and temporarily stored at a designated location. These materials shall be disposed of as general refuse. General refuse will be placed in plastic bags and then into an on-site dumpster.

5.1 Personnel Decontamination

Personnel decontamination will be accomplished by following a systematic procedure of cleaning and removal PPE. Contaminated PPE such as boots and face shields will be rinsed free of gross contamination, scrubbed clean in a detergent solution and then rinsed clean. When personnel decontamination is necessary, a three-basin wash system will be set up within the active contamination reduction zone.

Disposable PPE, such as Tyvek coveralls, gloves, outer boots, etc. will be disposed of as general refuse. Respirators will be cleaned after each use with respirator wipe pads and will be stored in plastic bags after cleaning.

5.1.1 Decontamination Sequence

(Note: Steps required will depend on the level of protection worn).

1. Remove and wipe clean hard hat

2a. Rinse boots and gloves of gross contamination

2b. Scrub boots and gloves clean

2c. Rinse boots and gloves

3. Remove outer boots

4. Remove outer gloves

5. Remove tyvek coveralls

6. Remove respirator, wipe clean and store

7. Remove inner gloves

Boots that have been decontaminated can be worn into the support zone.

5.2 Equipment Decontamination

Appropriate measures should be taken to prevent unnecessary or avoidable equipment contamination. Sampling devices routinely become contaminated. However, monitoring instruments can and should be handled in a manner which avoids direct/physical contact with solid or liquid contamination which could leave residual deposits on the instrument. Once contaminated, instruments are difficult to clean without damaging them. Any delicate instrument which cannot be easily decontaminated should be protected while it is being used. It should be placed in a clear plastic bag, and the bag taped and secured around the instrument. Openings are made in the bag for sample intake and exhaust.

If solvents are used for decontamination of equipment all safety precautions specified on the manufacturer's warning label and MSDS must be observed. Solvents or rinsate generated during the decontamination process will be drummed, labeled, and disposed of with other substances from the site. **Never use organic solvent to clean skin!**

Wooden tools are difficult to decontaminate because they absorb chemicals. They should be kept on site and handled only by protected workers. At the end of the field activities, wooden tools should be discarded.

Drilling rigs, Geo-Probes, truck, backhoes, and other mechanical equipment are difficult to decontaminate. The method generally used is to wash them with water under high pressure or to scrub accessible parts with detergent/water solution under pressure.

In some cases, shovels, scoops and augers may require steam cleaning. Particular care must be given to those components in direct contact with contaminants.

Personnel performing decontamination methods capable of generating airborne contaminants (dusts, mists, aerosols, etc.) must do so in Level C PPE. Otherwise, Level D or Modified Level D PPE should be worn.

TABLE 5-1
DECONTAMINATION PROCEDURES

Item	Examples	Procedure
Field Personnel	Hands, face and any exposed skin	■ Practice prevention; minimize exposure to contaminated materials through the proper use of PPE. ■ Wash with detergent and water; rinse with water.
Field Equipment	Bailers, interface probes, hand tools, and miscellaneous sampling equipment	■ Decontaminate with a solution of detergent and water; rinse with water prior to leaving the site. ■ Protect from exposure by covering with disposable covers such as plastic to minimize required decontamination activities.
Disposable PPE	Tyvek® suits, inner latex gloves, respirator cartridges	■ Dispose of according to the requirements of the base and state and federal agencies.
Nondisposable PPE	Respirators	■ Wipe out respirator with disinfecting pad prior to donning. ■ Decontaminate on site at the close of each day with a solution of an approved sanitizing powder and water.
	Boots and gloves	■ Decontaminate outside with a solution of detergent and water; rinse with water prior to leaving the site. ■ Protect from exposure by covering with disposable covers such as plastic to minimize required decontamination activities.

6.0 MEDICAL SURVEILLANCE

6.1 General

Personnel covered by this SSHP must be active participants in Groundwater Technology Medical Monitoring Program or in a similar program which complies with OSHA 29 CFR 1910.120(f), ANSI Z88.2 and the USACE Safety and Health Requirements Manual EM 385-1-1, Appendix K. Each individual must have completed an annual surveillance examination and/or an initial baseline examination within the last year prior to performing any work on this site covered by this SSHP.

6.2 Medical/Technical Advisors

Stephen Venuti, C.I.H., Health and Safety Manager Groundwater Technology Government Services, Inc., Norwood, MA	(617) 769-7600 x 358
David Crowley, C.S.P., C.E.T., C.H.M.M. Groundwater Technology, Inc., Norwood, MA	(617) 769-7602
Katy Perkoski, R.N., C.O.H.N. Groundwater Technology, Inc., Norwood, MA	(617) 769-7600
Ben Hoffman, M.D., Consulting Medical Director	(603) 778-9426

The specific duties of the Medical/Technical Advisors include:

- providing technical input into the design of the site safety and health plan,
- advising worker exposure potential along with appropriate hazard reduction methods, and
- recommending a suitable medical monitoring program for the site workers.

7.0 AIR MONITORING

Air monitoring action levels have been developed to indicate the chemical concentrations in the breathing zone that require an upgrade in level of PPE. General guidelines are presented in Table 7-1. All workers on-site have been properly fitted with PPE (i.e. respirators) and have been trained in their use (i.e. donning and doffing). Air monitoring measurements will be taken in the breathing zone of the worker most likely to have the highest exposure.

Transient peaks will not automatically trigger action. Action will be taken when levels are consistently exceeded in a 5-minute period. The action levels apply to all tasks performed on this site.

Air Monitoring falls into two separate categories; direct reading/environmental monitoring, and personal exposure monitoring.

7.1 Environmental Monitoring

The required environmental monitoring will be conducted using the direct reading instruments as indicated in Table 7-2. Data provided by these instruments will be used to determine the appropriate control actions and personal protective equipment requirements.

Equipment calibration must be performed in accordance with the manufacturers instructions. Field checks using the appropriate reference standards must be made on site at the minimum frequency of twice per shift (pre and post sampling). A daily log of all instrument readings, as well as all field reference checks and calibration information must be maintained. Field calibration logs are provided in Appendix B-6.

All air monitoring data must be recorded on the Vapor Monitoring Sheet (Appendix B-5).

TABLE 7-1
GENERAL AIR MONITORING GUIDELINES

Conduct periodic monitoring when: (1) it is possible that an immediate danger to life and health (IDLH) condition or a flammable atmosphere has developed or (2) there is an indication that exposures may have risen over permissible exposure limits or published exposure levels since the last monitoring. Look for a possible rise in exposures associated with these situations:

- **Change in Site Area** - work begins on a different section of the site
- **Change in Contaminants** - handling contaminants other than those first identified
- **Perceptible chemical odors or symptoms of exposure**
- **Change in On-Site Activity** - one operation ends and another begins
- **Handling Leaking Drums or Containers**
- **Working with Obvious Liquid Contamination** (e.g, a spill or lagoon)

1. Conduct air monitoring when the possibility of volatilization exists (such as with a new monitoring well or a well containing known product).

2. Conduct air monitoring on a well at a site known to have little contamination (documented by experience or laboratory data) **only** if an odor emanates from the well.

3. Conduct air monitoring during monthly operation and maintenance visits.

4. No air monitoring is anticipated for weekly site visit for system operation, unless vapor wells are opened or active vapor extraction (versus air injection) is conducted.

TABLE 7-2: VAPOR MONITORING GUIDELINES

Chemical			Exposure Limits		Instrument			Required Action	Sample/ Monitoring Frequency
Identification	Vapor Pressure VP (mmHg)	Ionization Potential IP (eV)	OSHA PEL (ppm)	ACGIH TLV (ppm)	Type	Relative Response	Reading		
JP 4/Total VOCs as:					PID (10.2 lamp/isobutylene std.)		Any sustainable reading above background	• Sample for Benzene	Sample with PID throughout active (soil gas survey, drilling, Geo-Probe, Bioventing startup) operations as detailed in Table 7-1.
Ethyl-Benzene	10 (79°F)	8.76	100	100		1:1	≥ 25ppm	• Upgrade to Level C	
Toluene	20 (65°F)	8.82	50 [skin]	50 [skin]		1:1	≥ 100ppm Same	• Leave area. Re-assess control options and project scope	Vapor
Xylene	9	8.56	100	100		1:1.1	Same		

TABLE 7-2: VAPOR MONITORING GUIDELINES

Chemical			Exposure Limits		Instrument			Required Action	Sample/ Monitoring Frequency
Identification	Vapor Pressure VP (mmHg)	Ionization Potential IP (eV)	OSHA PEL (ppm)	ACGIH TLV (ppm)	Type	Relative Response	Reading		
JP 4/Total VOCs as:					PID (10.2 lamp/isobutylene std.)		Any sustainable reading above background	• Sample for Benzene	Sample with PID throughout active (soil gas survey, drilling, Geo-Probe, Bioventing startup) operations as detailed in Table 7-1.
Ethyl-Benzene	10 (79°F)	8.76	100	100		1:1	≥ 25ppm ≥ 100ppm	• Upgrade to Level C • Leave area. Re-assess control options and project scope	
Toluene	20 (65°F)	8.82	50 [skin]	50 [skin]		1:1	≥ 25ppm ≥ 100ppm		Vapor
Xylene	9	8.56	100	100		1:1.1	≥ 25ppm ≥ 100ppm		
Benzene	75mm	9.24 eV	1 [TWA] 5 [STEL]	10	Color indicator tube (Draeger/Sensidyne)	± 25%	≥ 0.5ppm ≥ 15ppm	• Upgrade to Level C • Leave area. Re-assess control options and project scope	Initiation of new task, new area or new task in same area.

TABLE 7-2: VAPOR MONITORING GUIDELINES

Chemical			Exposure Limits		Instrument			Required Action	Sample/ Monitoring Frequency
Identification	Vapor Pressure VP (mmHg)	Ionization Potential IP (eV)	OSHA PEL (ppm)	ACGIH TLV (ppm)	Type	Relative Response	Reading		
Combustible Gas (contingency only)	NA	NA	NA	NA	CGI (methane std)	NA	<10% LEL 10 to 25% LEL >25% LEL	• Continue to monitor with caution. Eliminate all ignition sources. • Shutdown operations, evacuate area, begin vapor control measures. Resample prior to reentry. • Explosion hazard; withdraw from area.	In the event of > 100 units (5 minutes sustained) as measured with PID or instantaneous reading ≥ 1,000 units as measured with PID.

Notes:

VOC	=	volatile organic compound
VP (mmHg)	=	vapor pressure in millimeters at Mercury at 68°F
IP (eV)	=	ionization potential in electron volts
OSHA PEL	=	Occupational Safety and Health Administration Permissible Exposure Limit
ACGIH TLV	=	American Conference of Governmental Industrial Hygienists Threshold Limit Value
ppm	=	parts per million
TWA	=	8-Hour Time-Weighted Average
STEL	=	Short-Term Exposure Limit
CGI	=	Combustible Gas Indicator

7.1.1 JP 4 as Total VOCs/BTEX Compounds

A PID, equipped with a 10.2 eV lamp, calibrated with isobutylene and referenced to benzene-in-air (or a flame ionizing detector [FID] calibrated with and reference to methane in air), will be used to monitor the breathing zone of workers to assess the potential presence of organic vapors. Benzene, ethyl benzene, toluene, and xylene each have **ionization potentials (IP)** below ten and will produce **relative responses (RR)** of approximate 1:1 using the PID as described above.

The SHSO must ensure that PID readings are conducted daily at the initiation of all activities within the scope of this project. Monitoring will continue throughout all activities at a frequency of at least once every 15 minutes or at some other frequency as determined by the SHSO.

Because of the low exposure limit of benzene (1 ppm), it is not easily detected by the PID (the exposure limit of benzene would be indicated by a barely noticeable meter deflection of 1 unit on a PID calibrated to benzene). Therefore, PID readings will be supplemented with specific color indicator tubes (Draeger, Sensidyne or equivalent) to detect the presence of benzene in the breathing zone of workers during investigative activities.

The SHSO will ensure that indicator tube readings are conducted whenever PID readings above background are sustained. Color indicator tube samples will be collected at least once immediately after the action is required by PID readings and repeated at a frequency to be determined by the SHSO.

Should the color indicator tube readings indicate breathing zone benzene levels of 0.5 ppm or greater, respiratory protection will be donned. If the color indicator tubes indicate that benzene is not present, the action level for donning respirators is 25 ppm on PID (one-half the TLV for toluene). Should tubes indicate concentrations of benzene are present in worker breathing zones above 15 ppm, work will be stopped so that the scope can be re-evaluated and this SSHP modified accordingly. If color indicator tubes indicate a level of benzene above the Level C action level, representative sampling in accordance with NIOSH/OSHA sampling protocol may be required for affected employees.

7.1.2 Dust Monitoring

Field activities will not produce dust at the sites under this WAD. Dust monitoring other than visual observation will not be conducted during field activities.

7.1.3 Confined Space Entry

No confined space/limited egress tasks are to be performed within the scope of this SSHP.

7.1.4 Combustible Gas Indicator (CGI)

Allowing for the possibility that flammable materials may be encountered on site, steps necessary to minimize fire and explosion must be observed. If excessive organic vapors or free product are encountered, monitoring with a CGI calibrated using methane as a reference standard will be required. Appropriate response actions are described in Table 7-2.

7.2 Personal Exposure Monitoring

According to OSHA 1910.120, personal exposure monitoring for the purpose of determining individual time-weighted average exposures is required during certain site cleanup or other remedial activities. Determinations regarding individual exposure potentials will be based on the work area monitoring described above. Separate personal air sampling will not be conducted.

8.0 PERSONAL PROTECTIVE EQUIPMENT

PPE will be donned as described below for the activities covered by this SSHP. Based on available analytical data and the nature of the sites (i.e., open) and the specified scope of activities, it is assumed that most activities will require Level D or Modified Level D. This plan also contains contingencies for upgrading to Level C.

Only PPE that meet the following ANSI standards may be worn:

- Eye protection - ANSI Z87.1-1989
- Head protection - ANSI Z89.1-1986
- Foot protection - ANSI Z41-1991

Prior to use, all equipment must be inspected to ensure proper working condition. Contact with contaminated surfaces, or surfaces suspected of being contaminated should be avoided. This includes walking through, kneeling or placing equipment in puddles, mud, discolored surfaces, or on drums and other containers. Eating, smoking, drinking and/or the application of cosmetics is restricted to the support zone and is prohibited in the immediate work area. When utilizing protective garments such as tyvek suits, gloves and booties, all seams between protective items will be sealed with duct tape. Limitations during temperature extremes, heat stress and medical considerations will be monitored by the SHSO for determination of work/rest regiment.

8.1 General Site Work

General site work (outside the active exclusion zones and/or CRZs) will require Level D protective equipment. This equipment is defined as:

- Work uniform/clothes (consisting of shirt and trousers)
- Steel-toed boots
- Approved safety glasses or goggles
- Hard hat
- Fluorescent vest, when vehicular traffic is on or adjacent to the site
- Ear plugs and muffs (if required)
- Nitrile gloves for water sampling handling

8.2 Drilling, Geo-Probe, Biovent Installation, Sampling and Soil Gas Survey

Modified Level D personal protective clothing will be worn during all intrusive and sampling activities where skin contact with contaminants is reasonably anticipated. This PPE is identified as the following:

- Work uniform/clothes (consisting of shirt and trousers)
- Steel-toed boots
- Approved safety glasses or goggles
- Hard hat
- Fluorescent vest, when vehicular traffic is on or adjacent to the site
- Ear plugs and muffs (if required)
- Nitrile gloves for water sampling handling
- Tyvek® suits, NBR outer and nitrile inner gloves if skin contact with contaminants is possible (Tyvek® suit is an option to be utilized at the discretion of the SHSO on his/her assessment of the conditions within the immediate work area).

8.3 Upgrade Contingency

If the Action Levels specify the need, the following Level C PPE will be required:

- NIOSH-approved full-face respirator with organic vapor/acid gas and or HEPA cartridges
- Work uniform/clothes (consisting of shirt and trousers)
- Steel-toed boots
- Hard hat
- Tyvek® suits, NBR outer and nitrile inner gloves, if skin contact with contaminants is possible (Tyvek® suit is an option to be utilized at the discretion of the SHSO on his/her assessment of the conditions within the immediate work area).

8.4 Decontamination

Personnel performing decontamination methods capable of generating airborne contaminants (dusts, mists, aerosols, etc.) must do so in Level C PPE. Otherwise, Level D or Modified Level D PPE should be worn.

9.0 RESPIRATORY PROTECTION PROGRAM

If required (based on air monitoring results), Level C respiratory protection will be worn, consisting of full-face air purifying respirator with combination dust and organic vapor cartridges. Furthermore, should dusty conditions prevail during soil boring or well installation, Level C respiratory protection will be donned.

All personnel who will be required to don air purifying respirators must have been qualitatively or quantitatively fit-tested for the particular brand and size respirator he/she will be wearing on site within the last year. The requirement to wear Level C during dusty conditions does not include normal situations such as gusts carrying New Mexico road dust. The SHSO must use his/her discretion in this regard.

Normal eyeglasses cannot be worn under full-face respirators because the temple bars interfere with the face seal. For workers requiring corrective face piece lenses, special spectacles designed for use with respirators must be available. Contact lenses should not be worn on site. However, ANSI Z88.2-1992 American National Standard for Respiratory Protection, paragraph 7.5.3.3 states that: "Contact lenses may be worn with respirators, provided the individual has previously demonstrated that he or she has had successful experience wearing contact lenses. The contact lens wearer shall practice wearing the respirator while wearing the contact lenses."

In the event that air monitoring results indicate the need to go to Level B protection (full-face, positive pressure or demand-mode supplied air breathing apparatus or equivalent), the scope and associated cost of this study may need to be re-evaluated.

10.0 TRAINING AND COMMUNICATION

10.1 General Training Requirements

Personnel covered by this SSHP must be active participants in Groundwater Technology Training Program or in a similar program which complies with OSHA 29 CFR 1910.120(e), OSHA 29 CFR 1926.20, and the USACE Safety and Health Requirements Manual EM 385-1-1 (Section 28.D).

Individuals who plan to work in the active/designated exclusion zones and/or CRZs where the potential for exposure to safety or health hazards exists must have completed an annual 8-hour refresher training course and/or initial 40-hour training course within the last year prior to performing any such work.

Also, at least one Groundwater Technology representative must be on site during all activities to act as the site manager and SHSO. This individual must have documentation of at least three days of supervised field experience as well as completion of the specified 8-hour training course for managers and supervisors.

10.2 On-Site Communications

Verbal communication at the sites may be impeded by on-site background noise or on-going activities, or the use of personnel protective equipment. Two-way radios will be used on-site (unless prohibited by Security) when communication is necessary between working zones or geographic features which may limit other forms of communication. Radio frequencies will be approved by the Air Force. Hand signals may be used between personnel and will be reviewed during daily safety/pre-shift meetings. The use of the "buddy system" will ensure that any information is communicated between all workers on-site. Visual contact must be maintained between pairs when respiratory protection is used.

External communications between on-site and off-site personnel will be conducted through the use of cellular telephone or pay phones located on/near the facility. Exact locations of

the telephones and numbers will be obtained before site activities begin and will be communicated to all site personnel.

10.3 Notification of Activities

Prior to starting work at the site, the base fire department and base and Alamogordo hospitals will be contacted by the SHSO regarding the scope of work, potential hazards at the site and to confirm that the emergency services are capable of handling an emergency situation.

10.4 Safety Orientation/Tailgate Meetings

A tailgate safety meeting will be given to the workers by the SHSO daily to review the chemical, physical and toxicological properties of the contaminants that may be present at the site. Proper and safe work practices will be reviewed. Contingency plans for potential emergency situations and location(s) of available safety equipment will be addressed at this meeting. The SHSO shall inspect the site to ensure that the SSHP is being properly implemented. The SSHP will be periodically reviewed to ensure that all physical and chemical hazards encountered during field activities are recognized and addressed by the SSHP.

11.0 SUBCONTRACTOR REQUIREMENTS

Subcontractors to Groundwater Technology will be required to provide to the Groundwater Technology Project (Site) Manager specific written documentation that each individual assigned to this project has completed the medical monitoring and training requirements specified above. This information must be provided prior to their performing any work on site.

12.0 FIRST AID PLAN

The following general guidelines will apply if the need for emergency first aid services arises:

1. Survey the situation. Do not endanger your own life. DO NOT ENTER A CONFINED SPACE TO RESCUE SOMEONE WHO HAS BEEN OVERCOME UNLESS PROPERLY EQUIPPED AND A STANDBY PERSON IS PRESENT.

2. Call the fire department IMMEDIATELY. Explain the physical injury, chemical exposure, fire, or release.

3. Decontaminate the victim without delaying life-saving procedures.

4. If the victim's condition appears to be noncritical, but seems to be more severe than minor cuts, he/she should be transported to the nearest hospital by trained Emergency Medical Services (EMS) personnel: Let the doctor assume the responsibility for determining the severity of the injury. If the condition is obviously serious, EMS must transport the victim.

5. When transporting an injured person to a hospital, bring this SSHP to assist medical personnel with diagnosis and treatment. In all cases of chemical overexposure, follow standard procedures as outlined for poison management, first aid, and, if applicable, cardiopulmonary resuscitation.

6. Notify the Project Manager and the SSHO. Complete the Preliminary Incident Report (Appendix A-4) within 24 hours.

TABLE 12-1 – EMERGENCY FIRST AID PROCEDURES	
To Stop Bleeding	**Cardiopulmonary Resuscitation (CPR)**
1. Give medical statement, that you are trained in first aid/CPR. 2. Assure airway, breathing, circulation 3. Use **DIRECT PRESSURE** over the wound with clean dressing or your hand (use nonpermeable gloves). Direct pressure will control most bleeding. 4. Bleeding from an artery or several injury sites may require **DIRECT PRESSURE** on a **PRESSURE POINT**. Use pressure points for 30-60 seconds to help control severe bleeding. 5. Continue primary care and seek medical aid as needed.	1. Give medical statement, that you are trained in first aid/CPR. 2. Arousal: Check for consciousness. 3. Open airway with chin-lift. 4. Look, listen, and feel for breathing. 5. If breathing is absent, give 2 slow, full rescue breaths. 6. Check the pulse for 5 to 10 seconds. 7. If pulse is present, continue rescue breathing: **1 breath every 5 seconds**

13.0 GENERAL SAFETY RULES

Precautions must be taken to prevent injuries and exposures to the following potential hazards.

TABLE 13-1
POTENTIAL HAZARDS AND CONTROL

Potential Hazard	Control
Exposure to Chemicals of Concern (See Appendices B-1: MSDS Definitions and B-2: MSDSs)	1. Stand up-wind of contaminants whenever possible. 2. Minimize contact and contact time with petroleum products. 3. Avoid walking through discolored areas, puddles, leaning on drums, or contacting anything that is likely to be contaminated. 4. Do not eat, drink, smoke and/or apply cosmetics in the hot or warm zones. 5. Wear gloves when in contact with contaminated surfaces. 6. Safety glasses must be worn at a minimum. 7. Splash goggles must be worn when working with liquids. 8. Refer to Section 7 for specific monitoring requirements and action levels. 9. >100 ppm organic vapors in breathing zone. **STOP WORK IMMEDIATELY-CONTACT SHSO AND HSM OR CIH.** 10. If unknown materials are encountered, call the SHSO.
Exposure to Surface/Subsurface Airborne Dust	1. Stand upwind whenever intrusive activities occur and generate visible signs of airborne dust. 2. Monitor air for airborne dust (surface or subsurface) 3. Utilize wet methods (spraying ground, wet drilling etc.) when visible signs of airborne dust is generated.
Inclement Weather	1. Stop outdoor work during electrical storms and other extreme weather conditions such as extreme heat or cold temperatures. 2. Take cover indoors or in vehicle. 3. Listen to local forecasts for warnings about specific weather hazards such as tornados, hurricanes and flash floods.
Noise	1. Wear hearing protection when equipment such as a drill rig, jackhammer, cut saw, air compressor, blower or other heavy equipment is operating on the site. 2. Wear hearing protection whenever you need to raise your voice above normal conversational speech due to a loud noise source; this much noise indicates the need for protection.

TABLE 13-1
POTENTIAL HAZARDS AND CONTROL

Potential Hazard	Control
Electric Shock	1. Maintain appropriate distance from overhead utilities; **20-foot minimum clearance from power lines required; 10-foot minimum clearance from shielded power lines.** 2. Use ground-fault circuit interrupters as required. 3. Perform lockout/tagout procedures (Appendix C-1). 4. Use three-pronged plugs and extension cords. 5. Contact your local underground utility-locating service. 6. Follow code requirements for electrical installations in hazardous locations.
Physical Injury	1. Wear hard hats and safety glasses when on site. 2. Maintain visual contact with the equipment operator and wear orange safety vest when heavy equipment is used on site. 3. Prevent slips, trips and falls; keep work area uncluttered.
Back Injury	1. Use a mechanical lifting device or a lifting aid where appropriate. 2. If you must lift, plan the lift before doing it.
Insects	1. Tuck pants into socks. 2. Wear long sleeves and use insect repellent.
Poisonous Plants (such as poison ivy, oak or sumac)	1. Do not enter areas infested with poisonous plants. 2. Immediately wash any areas that come into contact with poisonous plants.
Drilling	1. Inspect cables, ropes and hooks for wear. 2. Beware of slipping during damp or wet conditions. 3. Try to perform the work or rectify the problem from the ground.
Fire Control	1. Smoke only in designated areas. 2. Keep flammable liquids in closed containers. 3. Keep site clean; avoid accumulating combustible debris such as paper. 4. Isolate flammable and combustible materials from ignition sources.
First aid kit, emergency eye wash station, fire extinguisher and absorbent pads will be located on-site in the truck.	

14.0 VISITOR REQUIREMENTS

Visitors to the site will be required to participate in a site safety orientation briefing. In accordance with the contract requirements, Groundwater Technology will continuously maintain four sets of protective equipment (excluding respirators, prescription glasses and safety shoes), i.e., Modified Level D on site for government representatives.

15.0 EMERGENCY ACTION PLAN

15.1 General Requirements

OSHA defines emergency response as any "response effort by employees from outside the immediate release area or by other designated responders (i.e., mutual-aid groups, local fire departments, etc.) to an occurrence which results, or is likely to result in an uncontrolled release of a hazardous substance." Personnel covered by this SSHP are not expected to participate in an emergency response where there are potential safety or health hazards (i.e., fire, explosion, or chemical exposure). Response actions will be limited to evacuation and medical/first aid as described in Table 15-1.

TABLE 15-1
CONTINGENCY PLANS FOR SITE EMERGENCIES

Situation		Action	
1	Evacuation	1.	Immediately notify all on-site personnel of an emergency requiring evacuation to a designated rally point upwind of the site.
		2.	Leave the dangerous area.
		3.	Notify Emergency Services, as appropriate.
		4.	Account for all personnel.
		5.	Contact the PM and the SHSO as soon as possible.
		6.	Maintain site security and control measures for community safety until emergency responders arrive.

TABLE 15-1
CONTINGENCY PLANS FOR SITE EMERGENCIES

Situation		Action
2	**Contaminant Exposure**	1. Evaluate the situation before taking action. Do not enter a confined space to rescue someone who has been overcome unless properly equipped and a standby person is present. 2. Remove person from contaminated environment. 3. If decontamination can be done, wash, rinse and/or cutoff protective clothing and equipment, especially for heat stress related illness. 4. If decontamination cannot be done due to severity of injury/illness, wrap victim in blankets, plastic or rubber to reduce contamination of other personnel. Alert EMS personnel to potential contamination and instruct them about specific decontamination procedures. Transport to hospital with SSHP to assist medical personnel in diagnosis and treatment.
3	**Medical Emergency**	1. Survey the Situation: **Do not enter an area that may jeopardize your safety.** ■ Establish the patient's level of consciousness. ■ Call for help. ■ Contact Emergency Medical Services and inform them of patient's condition. ■ Provide EMS and hospital personnel with information on the chemical(s) that may exist. 2. Primary Assessment (patient unconscious) ■ Arousal ■ Airway ■ Breathing ■ Circulation **Only trained personnel should perform CPR or First Aid.** 3. Secondary Assessment (patient conscious) ■ Check for bleeding: Control with direct pressure. ■ Do not move patient (unless location is not secure). ■ Monitor vital signs. ■ Provide First Aid and CPR to the level of your training. ■ Contact the PM and SHSO as soon as possible. ■ Document the incident on Preliminary Incident Report form.

TABLE 15-1
CONTINGENCY PLANS FOR SITE EMERGENCIES

Situation		Action
4	**Fire Emergency**	1. **Evacuate the area.** 2. Notify the Fire Services (1117). 3. Extinguish small fires with an all-purpose extinguisher. 4. Contact the PM and SHSO. 5. Document the incident using the Preliminary Incident Report Form.
5	**Adverse Weather Conditions**	Refer to Section 16 of this SSHP.
6	**Spill/Release**	Refer to Section 17 of this SSHP. **All unplanned releases (spills) shall be reported to Holloman AFB and the USACE TM.** The generator is under obligation to report to the proper government agencies. If the spill extends into waterways, the Coast Guard and the National Response Center (1-800-424-8802) must be notified immediately by the base with his permission. Unless mandated by law, **no outside agency may be contacted without the explicit approval by the Air Force.**
Notifications: Complete a Preliminary Incident Report.		

15.2 Site Emergency Forms and Maps (To Be Posted On-Site!)

Contaminants of Concern: Petroleum Hydrocarbons/JP-4
Minimum Level of Protection: Modified Level D

Do not endanger your life. Survey the situation before taking any action.

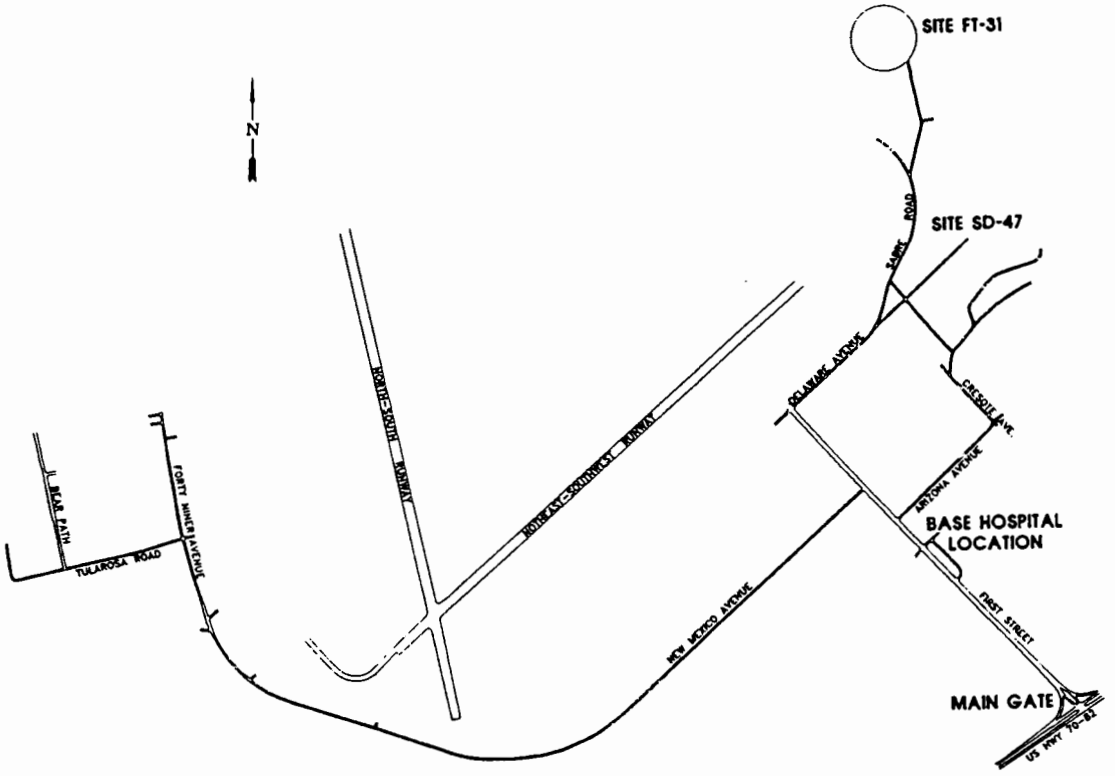
Groundwater Technology Office Telephone:	(505) 242-3113
Groundwater Technology Office Address:	2501 Yale Blvd. SE, Suite 204 Albuquerque, NM 87106 Fax: (505) 242-1103
Telephone Located at:	Phone On-site

IN THE EVENT OF ANY EMERGENCY, CONTACT PROJECT MANAGER OR SSHO

EMERGENCY PHONE NUMBERS

Ambulance (Base):	9-911	Project Manager:	Sara Brothers	(505) 242-3113
			(home)	(505) 345-3252
Fire Dept. (Base):	7228	Site Manager:	Chuck Schick	(505) 242-3113
Base Hospital:	7171	CIH:	S. Venuti	(617) 769-7600
			(home)	(617) 665-8603
Poison Control:	(800) 432-6866	DO Manager:	Ron Versaw	(303) 980-2202
EPA (info Line):	(800) 424-9346	Technical Mgr:	Mark Mercier	(402) 221-7666
Nat. Response Center:	(800) 424-8802	Base POC:	Warren Neff	(505) 479-3931
Chemtrec:	(800) 424-9300	On-site Foster Wheeler Representative:	Dan Holmquist	(505) 479-2668
State Agency:	N/A			
Base Hospital:	833rd Medical Group Hospital:			(505) 479-7171
Civilian Hospital:	Gerald Champion Memorial Hospital:			(505) 439-2100
Groundwater Technology Emergency Phone Number (24 hours):				(800) 876-0647

HOSPITAL LOCATION MAP



Hospital Directions: From FT-31: Go south from the site and turn left onto Sabre Road. Sabre Road turns into Delaware Avenue. Turn left onto First Street. Hospital on left side of road.

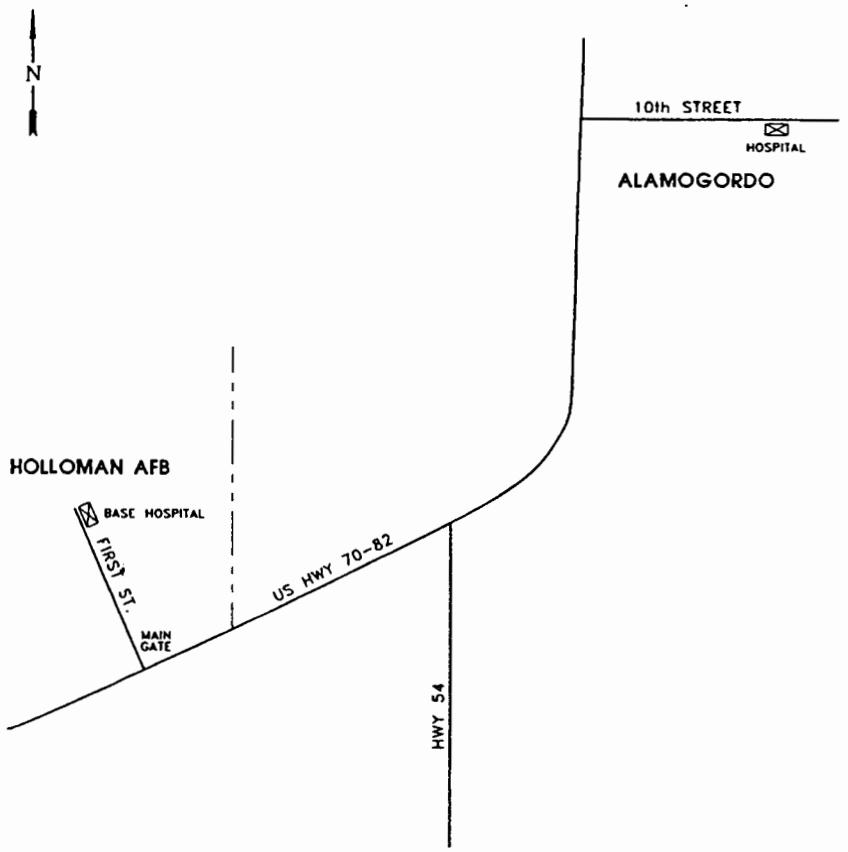
FROM SD-47: Proceed south on unnamed road that turns into Creosote Avenue. Turn right on Arizona Avenue. Turn left on First Street. Hospital is on the left side of the road.

Hospital Information:

Name	833rd Medical Group Hospital
Address	Santa Fe Street
City, State	Holloman AFB, NM
Phone	(505) 479-7171

Use in life threatening situations.

HOSPITAL LOCATION MAP



Hospital Directions: **From FT-31 to Main Gate:** Go south from site and turn left onto Sabre Road. Sabre Road turns into Delaware Avenue. Turn left onto First Street to get to the Main Gate.

From SD-47 to Main Gate: Proceed south on unnamed road that will turn into Creosote Avenue. Turn right on Arizona Avenue. Turn left on First Street to get to Main Gate.

From Main Gate. Turn left onto Hwy. 70/82. Turn right onto 10th Street. Hospital on left side of road.

Hospital Information:

Name	Gerald Champion Memorial Hospital
Address	1209 East 9th Street
City, State	Alamogordo, NM
Phone	(505) 439-2100

Use in non-life threatening situations.

15.3 Incident Reporting Procedures

In addition to current Groundwater Technology Accident/Incident Reporting Policies and Procedures, accident prevention plans need to be addressed on a site-specific basis. The following outlines such needs:

- Administrative responsibilities including identification and accountability for accident prevention.
- Work plans to control/coordinate all phases of the work, including subcontractors.
- Initial site specific training/indoctrination.
- Plans for traffic control, noise control, temporary building/structure layouts (including electrical diagrams), fire protection, emergency services access, job site inspections and routine maintenance/cleanup, and any local ordinance compliance issues.
- Accident Investigation procedures pursuant to USACE EM 385-1-1, Section 2.

In the event of an accident or incident, a Preliminary Incident Report (Appendix A-4) must be completed within 24 hours. This is a Groundwater Technology internal reporting document. Depending upon the nature of the incident, additional agencies or individuals that may need to be notified include the EPA, NMED, OSHA, or Base POC. **All accidents and/or injuries shall be reported to Holloman AFB and the USACE TM.** Unless otherwise mandated by law, **no outside agency may be contacted without explicit approval by the Air Force.** The table below provides a summary of incident reporting guidelines.

TABLE 15-2

INCIDENT REPORTING GUIDE

Incident Class		
Class I: A minor incident that is dealt with at the local level.	Class II: A serious incident that requires notification to Corporate within 24 hours	Class III: A highly significant incident requiring immediate notification and assistance from Business Unit and Corporate
Examples of Incidents		
• First Aid injury • Minor damage to property (less than $200) • Non-reportable quantity spill • Near miss incident • Unsafe condition or action Note: If there is a question as to Class I or II, follow Class II notification actions.	• Personal injury (more than first aid to employee, sub-contractor or public) • Vehicle accident involving injury or damage to vehicle or property • Damage to property greater than $200 but less than $10,000 • Near miss incident that could have been very serious • Fire/Explosion • Non-emergency notification of regulatory agency is required • Served with subpoena (DO NOT ACCEPT, have delivered to CT Corporation System, Registered Agent)	• Hospitalization (of one or more persons) • Unprotected chemical exposure • Death • Damage to property greater than $10,000 • Regulatory agency response to incident site • Multiple injury of employees, sub-contractors or public • Emergency notification of regulatory agency • Site visit from regulatory agency • Contact or appearance of news or public media

TABLE 15-2

INCIDENT REPORTING GUIDE

Incident Class		
Class I: A minor incident that is dealt with at the local level.	Class II: A serious incident that requires notification to Corporate within 24 hours	Class III: A highly significant incident requiring immediate notification and assistance from Business Unit and Corporate
Notification Actions		
1. On-scene person notifies Manager immediately by phone 2. Provide PIR form to Manager within 24 hours 3. Manager investigates and follows up	1. On-scene person notifies Manager immediately by phone 2. Manager investigates 3. Manager notifies the Business Unit Manager, H&S Manager and Corporate Director H&S with PIR form within 24 hours of the incident 4. Manager provides a detailed final investigation report within 30 days to Business Unit Manager, H&S Manager and Corporate Director H&S	1. On-scene person notifies Manager immediately by phone 2. Manager immediately notifies Business Unit Manager, H&S Manager, and Corporate Director H&S (1-800-876-0647, Mailbox #11911) by phone. PIR form is provided by fax immediately to (1-617-769-9861) addressed to Corporate Director H&S 3. Incident management team conferences by phone and formulates an action plan

Any incident (other than minor first aid treatment) resulting in injury, illness or property damage requires an accident investigation and report. The investigation should be initiated as soon as emergency conditions are under control. The purpose of this investigation is not to attribute blame but to determine the pertinent facts so that repeat or similar occurrences can be avoided.

The investigation should begin while details are still fresh in the mind of anyone involved. The person administering first aid may be able to start the fact gathering process if the injured are able to speak. Pertinent facts must be determined. Questions beginning with who, what, when, where, and how are usually most effective to discover ways to improve job

performance in terms of efficiency and quality of work, as well as safety and health concerns.

16.0 HURRICANE AND DESTRUCTIVE WEATHER RESPONSE PLAN

Work will not be permitted during severe weather conditions or if there is an imminent threat of severe weather conditions which threaten the health and safety of on-site workers. Additionally site workers are advised to:

1. Stop work during electrical storms and other extreme weather conditions such as extreme heat or cold temperatures.

2. Take cover indoors or in vehicle.

3. Listen to local forecasts for warnings about specific weather hazards such as tornados, flash floods or electrical storms.

4. Take frequent work breaks during extreme heat or cold conditions.

17.0 SPILL PREVENTION AND CONTROL

Prevent problems by documenting the location of underground lines (e.g. product, sewer, telephone) before starting site work. If you rupture a line or tank or another leak occurs, document the spill or release in writing. Include dates, times, actions taken, agreements reached and names of people involved. In the event of a spill or release, the Foster Wheeler Spill/Release procedures (Appendix C-3) must be followed.

1. Wear appropriate PPE; stay upwind of the spill/release.

2. Turn off equipment and other sources of ignition.

3. Conduct defensive measures to stop the flow or basic containment of the spill (i.e., turn off pumps and shut valves to stop the flow/leak, plug the leak or collect drippings in a bucket, when possible, and place sorbent pads to collect product, if possible.)

4. Call Fire Department immediately if fire emergency develops.

5. Inform Groundwater Technology PM about the situation.

6. Determine if the Base wants Groundwater Technology to repair the damage or if the base will use an emergency repair contractor.

7. Based on agreements, contact emergency spill contractor for cleaning up the impacted material.

8. Advise the Base of spill discharge notification requirements and determine who will complete and submit forms. Do not submit or report to agencies without the Base's consent. Document each interaction with the Base and regulators and note, in writing: name, title, authorizations, refusals, decisions, and commitments to actions.

9. Do not transport or approve transportation of contaminated material until proper manifests have been completed and approved. Be aware that soils/product may meet criteria for hazardous waste.

10. Do not sign manifests as generator of waste; contact the regional compliance manager to discuss waste transportation.

All unplanned releases (spills) shall be reported to Holloman AFB and the USACE TM. Unless mandated by law, **no outside agency may be contacted without the explicit approval of the Air Force.**

Note: Complete a Preliminary Incident Report.

APPENDIX A

ADMINISTRATIVE INFORMATION

APPENDIX A-1

AGREEMENT AND ACKNOWLEDGEMENT SHEET

APPENDIX A-1: AGREEMENT AND ACKNOWLEDGEMENT SHEET

Groundwater Technology personnel have the authority to stop field activities at this site if any activity is not performed in accordance with the requirements of the Site Safety Plan. All Groundwater Technology project personnel, subcontractor personnel and visitors are required to sign the Agreement and Acknowledgement Sheet **prior** to conducting field activities at this site.

APPENDIX A-1
GROUNDWATER TECHNOLOGY, INC.
AGREEMENT AND ACKNOWLEDGEMENT SHEET

1. **I have been made aware of and fully understand the SHSP and my responsibilities.**
2. **I agree to abide by the provisions of the SHSP.**

Name	Signature
Company	Date
Name	Signature
Company	Date
Name	Signature
Company	Date
Name	Signature
Company	Date
Name	Signature
Company	Date
Name	Signature
Company	Date
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Company	Date
Name	Signature
Company	Date

APPENDIX A-2

AMENDMENT SHEET

APPENDIX A-2: AMENDMENT SHEET

Project Name: _____

Project Number: _____

Project Manager: _____

Location: _____

Changes in field activities or hazards:

Prepared by: _____ _____
Health and Safety Manager **Date**

Approved by: _____ _____
Certified Industrial Hygienist **Date**

APPENDIX A-3

VISITOR/TRAINEE GUIDELINES

APPENDIX A-3: VISITOR/TRAINEE GUIDELINES

Groundwater Technology, Inc. is committed to providing a safe environment on all work sites for visitors, trainees, employees and/or passersby. In order to accomplish this, the following guidelines must be followed.

1. VISITORS

Any person not actively participating in the work at the site is regarded as a "visitor" and must follow Groundwater Technology's visitor/trainee guidelines. Visitors must be accompanied by a representative while on site.

Sites must be marked with signs, placards, and/or barricades to designate hazardous boundaries. Visitors will not be allowed on any site that is not adequately marked.

2. TRAINEES

Trainees are employees of Groundwater Technology who have not yet completed Groundwater Technology's required safety training program. New hires and in-house company transfers will be considered trainees until safety training requirements are met.

Trainees will be informed of restrictions by their supervisor and must abide by them before visiting active sites.

Trainees will be permitted to visit Groundwater Technology sites as observers as long as the following conditions are met:

- Trainees are supervised at all times while observing on site.
- Trainees do not perform work functions of any type while on site.
- Trainees do not handle any equipment, tools and/or supplies while on site.
- Trainees do not enter any hazardous or hot zone or confined space areas while on site.

Supervisors will be responsible for informing trainees of the above conditions and for ensuring that the conditions are met. Supervisors will also ensure that trainees will not be asked to violate the conditions listed above.

A Trainee/Observer Agreement Form must be signed by both the trainee and the supervisor and placed on file in the Regional Human Resources department.

Infractions of the above agreement will be viewed as extremely serious and will be subject to discipline up to and including termination for either the trainee and/or supervisor.

TRAINEE/OBSERVER AGREEMENT FORM

Groundwater Technology is committed to providing a safe working environment for all employees. In addition, Groundwater Technology will comply with OSHA requirements for employee safety training prior to working on any hazardous site.

The following section is to be filled out by trainee.

Agreement between:

____________________________ ________________ and Groundwater Technology.
Name (print/type) SS#

Because we have your safety in mind, you will be considered a trainee until all training criteria are met. This means you must complete all training requirements prior to performing work activities on site. As a requirement of the training program, you will be asked to visit Groundwater Technology sites as an observer. You must be supervised on all of these site visits.

As an on-site observer trainee, your signature below indicates your agreement to these restrictions.

You may not:

1. Perform work functions of any type.
2. Handle any equipment/tools and/or supplies of any type.
3. Enter any hazardous or hot zone areas.

I agree to adhere to the above conditions in all instances while on site as a trainee/observer.

____________________________ ________________
Signature Date

- -

This section is to be filled out by supervisor.

As supervisor to the above trainee, I agree to the above restrictions and agree not to request him/her to perform activities contrary to those restrictions.

____________________________ ________________
Signature Date

APPENDIX A-4

PRELIMINARY INCIDENT REPORT

APPENDIX A-4: PRELIMINARY INCIDENT REPORT

Person Completing Report _____ Phone _____ Today's Date ____

Incident Date _____ Time: ____ am / pm Location _ Dept. #

Type of Incident:

- ☐ Personal Injury/Illness
- ☐ Unsafe Condition/Action
- ☐ Property Damage
- ☐ Permit/Code Compliance
- ☐ Fire/Explosion
- ☐ Equipment Damage
- ☐ Spill/Release
- ☐ Newspaper/Radio/ Television
- ☐ Chemical Exposure
- ☐ Customer Incident
- ☐ Near Miss
- ☐ Motor Vehicle
  Call Associates Leasing at 1-800-255-2607 if GTI vehicle involved

☐ Other _____

Personal Injury ☐ Yes ☐ No (If no, go to next section)

☐ First Aid Only ☐ Hospitalization ☐ Medical Treatment ☐ Possible Injury, Not Confirmed

Person Injured: ☐ GTI Employee ☐ Subcontractor ☐ Customer/Public/Other

Injured Name _____ Telephone _____

Office/Addres _____

Nature of Injury, Illness or Exposure _____

_____

_____

Describe nature of incident, how it occurred, who was involved, witnesses and possible causal factors:

_____

_____

_____

Describe actions taken and persons notified:

_____

_____

_____

Manager Responsible for Follow-up _____ Telephone _____

Provide this report to the responsible manager within 24 hours. Notify Corporate at (800) 876-0647, Mailbox 11911, of all Class II and III incidents and fax to (617) 769-9861 within 24 hours.

Distributed To: _____, _____,

_____, _____

Rev. 12/94

APPENDIX B

CHEMICAL PROFILES

APPENDIX B-1

GROUNDWATER TECHNOLOGY, INC.
HAZARD AND CONTAMINATION PROGRAM

GROUNDWATER TECHNOLOGY, INC.
HEALTH & SAFETY POLICY & PROCEDURE No. 9

HAZARD COMMUNICATION PROGRAM

1.0 Purpose:

This document specifies requirements and documentation required for implementing Groundwater Technology, Inc.'s ("GTI") Hazard Communication Program. The purpose of this program is to help Groundwater Technology employees safely perform their work. Hazard Communication represents one of the elements of the safety program for protecting Groundwater Technology Employees. This program is a legal requirement under OSHA standard 29 CFR 1910.1200.

2.0 Policy:

All Groundwater Technology employees and Subcontractors shall receive the appropriate training and guidance to achieve understanding of the chemical, physical and biological hazards they may encounter with their work, and to perform their tasks safely.

3.0 Responsibilities:

The responsibilities and role(s) are described:

Manager: Shall assure that appropriate information is provided to each Groundwater Technology employee in their business unit according to the specifications of this program. Shall assure the availability of hazard communication materials. The manager shall assign a trainer for communicating and documenting this training. The manager shall assure the training is adequate and that documentation is present by techniques such as inspection, attendance in training, and audits of the program.

Assigned Trainer: Shall cover the assigned task of presenting, showing the location for and using available Hazard Communication materials. The trainer shall provide written documentation of all Hazard Communication training.

Health and Safety Representative: Shall act as a technical resource to provide materials or content such as Material Safety Data Sheets or selection criteria for specific chemical resistance barriers. Where qualified, the Health and Safety Representative may perform this Hazard Communication training.

Employee: Shall complete all required Hazard Communication training prior to working with hazardous materials and perform work tasks. Each employee has the right to know when a potential for exposure to a hazardous material exists. The Employee is responsible to perform his/her duties in a safe manner and in conformance with company standards, Federal, state, and local regulations.

4.0 Requirements, Standards and Program Elements:

The Groundwater Technology requirements for all business units is to assure no employee is exposed to tasks with potential for hazards without having first completed Hazard Communication training that instructs the harmful effects, the pathways for exposure, the barriers and personal protection to put on, and safe guidelines for handling and doing the job. The Hazard Communication program elements are described in the addendum portion of this document.

5.0 References:

This program conforms to requirements set forth in the U.S.A. by OSHA 29 CFR 1910.1200.

6.0 The following documents and information tools should assist the business unit in implementing the policies and requirements for delivering Hazard Communication to Groundwater Technology employees, subcontractors, customers and the community as needed. These materials are to be used as guidelines and recommendations for Hazard Communication program content. Some of the Hazard Communication training program elements that should be included:

- Hazard Communication Program
- Employee Right to Know Responsibilities
- Hazardous Material and Chemical Product Labels (Exhibit A)
- Pipe Labeling
- Hazard Area Warning Signs (Exhibit B)
- Material Safety Data Sheets (Exhibit C)
- Request for MSDS Sample letter (Exhibit C)
- Chemical Inventory (Exhibit D)
- Hazard Communication Training
- Hazard Communication Documentation Procedures
- Hazard Communication Training Documentation Forms (Exhibit E)
- Audit for Hazard Communication (Exhibit G)

GROUNDWATER TECHNOLOGY, INC.
HEALTH & SAFETY POLICY & PROCEDURE No. 9

HAZARD COMMUNICATION PROGRAM

1.0 Health and Safety Policy for Hazard Communication:

- 1.1 Inventory Hazards:
  - 1.1.1 for office
  - 1.1.2 for field sites
- 1.2 Assess Hazards sources and tasks
- 1.3 Devise precautions for each hazard area or task
- 1.4 Train employees to avoid hazards and use hazard controls
- 1.5 Keep documentation records for all hazard controls and hazard communication training
- 1.6 No employee may work in the field without first completing all required training.
- 1.7 An appropriate site safety plan and waste notification form must be established for every field project.
- 1.8 All accidents and injuries must be reported and properly recorded.
- 1.9 No Groundwater Technology employee may enter a confined space until a qualified supervisor has determined that confined space entry requirements have been met.
- 1.10 Required safety equipment must be available and employed at Groundwater Technology sites.
- 1.11 Unsafe or questionable procedures must be corrected immediately.
- 1.12 Employee health monitoring must be completed prior to field work.
- 1.13 Fit testing and clearance for respirator use is required prior to donning a respirator.
- 1.14 Hazardous materials will be handled in accordance with all regulatory standards.
- 1.15 Job site recordkeeping must include employee exposure (air monitoring) data.
- 1.16 It is the responsibility of each Groundwater Technology employee to adhere to these policies and ensure his/her personal safety and the safety of coworkers.

Note:
The Hazard Communication Program and procedures are administered by the Corporate Health and Safety Director.

2.0 Health and Safety Managers and representatives maintain a master file of current updated Material Safety Data Sheets ("MSDS") representing chemicals used on Groundwater Technology Locations. *Note: Manufacturers publish updated MSDS Sheets annually.*

3.0 Managers are responsible for current MSDS Sheets for chemicals in use in their office, warehouse and field locations, which will be kept in the Right to Know Stations MSDS notebook, and for field sites attached to the specific site safety plan for each location.

4.0 Managers are responsible for obtaining current appropriate, legible MSDS sheets (Exhibit C), Hazard Warning Signs (Exhibit B) Hazard Labeling for Containers (Exhibit A), Hazard Pipe Labeling, and chemical inventory sheets (Exhibit D), electrical hazards labeling (see Exhibit F) for warehouses, project sites and offices.

5.0 Managers shall provide appropriate hazard communication training to employees, and assure proper communication materials are at the site Health and Safety Representatives may provide the technical assistance and training for these employees.

6.0 Hazard Communication training for employees will utilize the following types of information sources:

- Chemical Material Safety Data Sheets (MSDS)
- Container Hazard Labels: D.O.T., E.P.A., NFPA, HMIS
- Product Hazard information sheets (Manufacturer)
- Hazardous Chemical Warning sheets (ACGIH - Biological Exposure Indices)
- Hazard warning signs (OSHA)
- Written Hazard Communication Plan (HCP) for each office, site (Site Safety Plan)
- Site Safety Plan (Every field project site)
- Standard Operating Procedure (SOP) (Correct methods for performing the work)
- Task or job guideline sheets (Engineering and Safety guides for wrk)

7.0 Hazard communication training shall occur before any Groundwater Technology employee is authorized to begin work or could potentially be exposed to a hazard. Part of hazard communication is a discussion of employee rights and responsibilities.

8.0 Site specific hazard communication shall occur prior to the employee's first day at work on the site.

9.0 Hazard communication for all Groundwater Technology employees on hazardous sites include:

9.1 40 hours of hazardous waste site activities safety training (certificate)(or equivalent certificate) [29 CFR 1910.120]

9.2 3 days (24 hours) field orientation by a supervisor to hazardous site activities (documented) [29 CFR 1910.120]

9.3 Chemical, Biological, and Physical hazard communication prior to contact or exposure (documented)[29 CFR 1910.1200]

9.4 Site specific training by the Manager shall ensure the employee understands:

- the potential for chemical, biological, or physical injury
- the proper method or guideline for working safely
- the appropriate personal protective equipment to wear to prevent injury
- the standard operating procedures for doing the task safely.

Employee Rights and Responsibilities

OSHA (For U.S. Operations)

The Occupational Safety and Health Act of 1970 created the Occupational Safety and Health Administration (OSHA) within the Department of Labor. OSHA was chartered to develop and enforce workplace health and safety standards. It has promulgated this standard in 29 CFR 1910.1200.

Employee Right-To-Know

Groundwater Technology has established a written, comprehensive hazard communication program that includes provisions for container labeling, Material Safety Data Sheets and an employee training program. This program shall include a list of the hazardous chemicals in each work area, the means that Groundwater Technology uses to inform employees of the hazards of non-routine tasks (for example, the cleaning of reactor vessels), hazards associated with chemicals, and the way Groundwater Technology managers will inform other employers (e.g., sub-contractors) of the hazards to which *p2025Xtheir employees may be exposed.

Employee Rights According to OSHA:

- Review copies of appropriate standards, rules, regulations and requirements that Groundwater Technology offices should have available for inspection by the employee.

- To have awareness and instruction about:

  - Chemical, Biological and Physical Hazards
  - Hazard warning signs, labels and safety tags
  - Material Safety Data Sheets for chemicals they handle or have exposure
  - Orientation to workplace safety procedures, rules and standards
  - The hazards and safety precautions to use
  - Emergency information for notification and response
  - New chemicals before employee starts the job

- Request information from Groundwater Technology managers on safety and health hazards in the workplace, precautions that shall be taken, and procedures that must be followed if an employee is involved in an accident or is exposed to toxic substances.

- Have access to relevant employee exposures and medical records information from the corporate health monitoring manager.

- Request that OSHA conduct an inspection if the employee believes hazardous conditions or violations of standards exist in the workplace.

- Have an authorized employee representative accompany the OSHA compliance officer during

the inspection tour. This provision would apply to our subcontractor's employees who are represented by a union.

- Respond to questions from the OSHA compliance officer, particularly if there is no authorized employee representative accompanying the OSHA compliance officer on the inspection "walkaround".

- Observe any monitoring or measuring of hazardous materials by Groundwater Technology or OSHA officers and see the resulting records, as specified under the Act and as required by OSHA standards.

- Have an authorized representative, or themselves, review the Log and Summary of Occupational Injuries (OSHA No. 200) at a reasonable time and in a reasonable manner. The OSHA 200 Log must be publicly posted each February.

- Object to the abatement period set by OSHA for correcting any violation in the citation issued to the employer by writing to the OSHA area director within 15 working days from the date the employer receives the citation. Groundwater Technology must publicly post any citations we receive for violation of OSHA regulations.

- Submit a written request to the National Institute for Occupational Safety and Health (NIOSH) for information whether any substance in the workplace has potentially toxic effects in the concentration being used, and have their names withheld from Groundwater Technology, if that is requested.

- Be notified by Groundwater Technology if it applied for a variance from an OSHA standard, and be able to testify at a variance hearing, and appeal the final decision.

- Be advised of OSHA actions regarding a complaint and request an informal review of any decision not to inspect or to issue a citation.

- File a section 11(c) Discrimination Complaint if punished for exercising the above rights or for refusing to work when faced with an imminent danger of death or serious injury.

Employee Responsibilities According to OSHA:

A Groundwater Technology employee should do the following:

- Read the OSHA poster at the Groundwater Technology job site

- Comply with all applicable OSHA standards

- Follow all Groundwater Technology safety and health rules and regulations, and wear or use prescribed protective equipment while working.

- Report hazardous conditions to the Groundwater Technology supervisor or manager.

- Report any job related injury or illness to the Groundwater Technology supervisor or manager and seek treatment promptly.

- Cooperate with the OSHA compliance officer conducting an inspection if he or she inquires about safety and health conditions in the workplace. (See steps for the employee to take during an OSHA inspection)

- Exercise rights under the OSHA Act in a responsible manner.

Steps for the Groundwater Technology Employee to Take During an OSHA Inspection

I. Identify the OSHA Inspector

a. Ask to see credentials
b. Write down the relevant inforation
- inspector's name
- agency affiliation
- telephone number
- action item: Why he's there on site

c. Ask to see documentation for the inspector's medical monitoring and 40-hour hazardous waste site training.

II. Notify the Groundwater Technology project manager and district health and safety specialist **immediately**.

III. Take documentation notes on:
a. What is said
b. What is seen
c. Who spoke to whom
d. Any samples or pictures taken
e. Any corrective actions done in the inspector's presence
f. Any activity, including where, when, who and what
g. Any other occurrence, even if minor

IV. If asked a question by the OSHA inspector and the employee does not know the answer, Do Not Bluff your Answer. Ask the inspector to put the question in writing. Never lie or fabricate an answer

V. Carefully review the Groundwater Technology site safety plan with the OSHA inspector

VI. If complaints initiated the inspection, find out the specifics of what the complaints were.

Hazardous Materials and Chemical Product Labels

1.0 Project managers, operations managers, supervisors, office safety coordinators and all other Groundwater Technology employees shall ensure that chemical, biological, other hazardous materials containers are properly labeled. This labeling of containers includes properly marking containers of hazardous waste.

2.0 Containers of hazardous materials used, stored or handled at GTI shall bear the following information:

- Identity of the chemical (or material), trade name and composition
- Appropriate hazard warnings: (flammable, corrosive, reactive, toxic, explosive)
- Name and address of chemical manufacturer, generator, responsible arty
- Product labels shall not be removed if the container still holds the original material
- NFPA labels, HMIS™ labels, chemical name labels shall be at each site.
- All secondary containers shall be marked with the same information as the original container.
- All hazardous waste containers shall be properly labeled.
- The site or office must have an MSDS for each chemical on site.
- A chemical inventory is required for all chemicals in use on each site.
- All chemicals in use at field sites must have a representative MSDS attached to the Site Safety Plan.
- Any changes in MSDS requires a hazard communication update to the employees by the manager, supervisor, project manager or office safety coordinator.

See Exhibit A – Examples of Hazardous Materials Container Labels

Pipe Labeling

1.0 Project managers, operations managers, supervisors, or office safety coordinators are responsible for assuring proper pipe labeling on project site installations, office and warehouse.

2.0 Managers and supervisors must include pipe labeling requirements in the hazard communication training.

3.0 All chemical and waste pipelines shall be properly labeled.

4.0 Examples of Hazard Color Coding for Pipe Labels

ANSI* Color Codes Corresponding to Chemical Hazard Codes	
ANSI Coding	**Definition**
yellow labels/black letters	hazardous
green label/white letters	low hazard (liquid)
blue label/white letters	low hazard (gas)
Red label/white letters	fire quenching materials

*ANSI - America National Standards Institute

5.0 Colored pipe labels shall be placed near each pipe joint, valve or bend and every 25 linear feet or less, (with directional flow colored arrows).

6.0 A colored pipe code key will be visible and prominently displayed at each area where pipes are coded and labeled. All pipes shall be appropriately labeled at each Groundwater Technology facility. (See section 7.0 for labeling key)

7.0 Standard Pipe labeling key for products in use at Groundwater Technology facilities:

Legend	Color	Legend	Color
Acid	yellow	oxygen	yellow
Air	blue	steam	yellow
Compressed Air	blue	BTEX	yellow
Exhaust Air	blue	Plumbing Vent	green
Ammonia	yellow	City Water	green
Caustic	yellow	Drain Water	green
Condensate	yellow	Non Potable Water	yellow
Domestic Water	green	Potable Water	green
Sanitary drain	green	Unsafe Well Water	yellow
Engine Exhaust	yellow	Peroxide	yellow
Sprinkler-Fire	red	Sulfuric Acid	yellow
Natural gas	yellow	Lime Mud	yellow
City Gas	yellow	Feed to Tower	yellow
Propane	yellow	Water	yellow
Hot Water	yellow	Chlorine	blue
Fuel Oil	yellow	Instrument Air	yellow
Suction	yellow	Waste Oil	green
		Deionized Water	yellow
		Carbon Dioxide	yellow
		Hydrogen	green
		Inert Gas	

Standard Electrical Circuit Hazard Labeling

1.0 Standard labeling of all electrical circuits in the wiring boxes is part of hazard communication.

1.1 Managers shall assure through inspection and training that all project site installations, offices, and warehouses have proper labeling of circuits in electrical control boxes.

1.2 Lockout/tagout labeling sources. See Exhibit F.

Hazard Area Warning Signs

1.0 Hazard signs shall be placed in appropriate positions at eye height to warn of potential hazards, special protective equipment zones and unauthorized entry areas.

2.0 General hazard communication training shall be performed by operations managers, project managers supervisors or office coordinators to assure all field or office employees understand the meaning and reason for erecting the signs.

See Exhibit B--Examples of OSHA Hazard Warning Signs

Material Safety Data Sheets (MSDS)

1.0 Operations Managers, project managers, supervisors and office safety coordinators are responsible to obtain and maintain an up to date file of all chemicals in use at the office, warehouse and all project sites and assure hazardous chemicals shall not be placed in service or use on sites until:

- An MSDS is available for the office file for all chemicals in use on project installations, offices, and warehouses.
- A copy is attached to the Site Safety Plan on each project site.
- A Hazard Communication Training Session with the MSDS has taken place for all employees with potential for exposure in attendance and documentation is placed in their training files

See Exhibit C: Examples of Material Safety Data Sheets (MSDS)

Chemical Inventory

1.0 In the event of a hazardous chemical exposure to any employee on a Groundwater site, the operations manager shall assure a copy of the MSDS will be sent to the appropriate medical facility and if possible transported with the exposed employee.

2.0 Operations managers, project managers, supervisors and office safety coordinators shall make available a master chemical inventory list for each site, and assure it is available for the local fire department. This contingency plan shall also have a floor plan of each facility and site with the location and legend of all chemicals on site. This plan shall be updated annually, in January.

See Exhibit D: Example of a Warehouse Chemical Inventory Sheet

2.1 Elements of the chemical inventory shall include:

- Maximum amount of hazardous chemical in each category
- Average daily amount for each hazardous chemical category
- General location for each category of hazardous chemical
- A brief description of how each category of hazardous chemical is stored
- Location for each hazardous chemical on each project installation, office and warehouse (floor plan)

Hazard Communication Training

1.0 Managers or their designee shall explain the elements of hazard communication and provide training for each employee, an outline of these elements include:

- Explanation of OSHA Hazard Communication Standard [29 CFR 1910.1200].
- Explanation of Groundwater Technology's responsibility in a Hazard Communication Program ("HCP").
- Demonstration, review and explanation of the written hazard communication plan available at the local office. All employees shall be told where the HCP is stored in the office.
- Show where the material Safety Data Sheets are stored
- Review all chemicals and hazardous chemicals are located or used in the local office that are available in the MSDS notebook.
- Discuss the work activities and environment that require hazardous chemicals and explain the engineering safeguards, personal protective equipment or standard operating procedures or methods used to avoid hazardous exposure.
- Explain or demonstrate proper procedures and equipment to sue for detecting the presence of hazardous materials.
- Discuss the routes for all hazardous chemicals to enter the body and the resulting effect on the body.
- Show the proper type of protective equipment to wear, discuss appropriate occasions for wearing the equipment, show where it is stored and proper methods for donning, doffing, and disposal of contaminated equipment.
- Explain the emergency procedures to follow for fires, personal injury, evacuation, chemical spills and other incidents.
- Discuss areas or activities on the sites that offer high risk for physical or biological exposures that will cause injury or illness to the employee.
- Explain to the employees what types of environmental monitoring or health monitoring is being done for employees working on site and documentation to be retained for thirty (30) years after termination.
- Explain that all MSDS files of currently used chemicals must be retained for thirty years and archived.

Managers are responsible to assure all employees have been trained in Hazard communication for all chemicals and other hazards before they encounter a potential exposure at the worksite.

NOTE: See documentation procedures for hazard communication and documentation forms in exhibit E.

Hazard Communication Documentation Procedures

1.0 Managers shall assure that hazard communication written documentation for all hazardous chemicals have been filed for each employee in their health and safety training folder, through inspections and audits.

2.0 Managers, shall audit and maintain accurate hazard communication documentation. See Exhibit E for forms.

3.0 Hazard communication training documentation must contain the following basic information:

- Employee's name
- Job Title
- Social Security Number
- Title of Course
- Description of Contents
- Number of hours training
- name of the instructor
- Date of training

4.0 Health monitoring results and confidential employee medical information are in the health and safety department. Requests for information should be made by contacting the corporate health monitoring manager.

5.0 It shall be assured that subcontractor personnel have received Hazard Communication training.

6.0 Subcontractor's employees must follow and obey all federal, state and local standards, as well as site safety plan requirements and safety guidelines in the employee safety handbook.

7.0 Subcontractor's employees must have the prerequisite 40 Hour and hazardous site orientation training before working on hazardous waste sites. Managers, project managers, supervisors and office safety coordinators must verify certificates and hazard communication training.

See Exhibit E--Initial Hazard Communication Form and Training Documentation

EXHIBIT A

SOURCES FOR ORDERING AND

EXAMPLES OF HAZARDOUS MATERIAL CONTAINER LABELS

HAZARD COMMUNICATION LABELS

SOURCES FOR ORDERING:

Seton Identification Products P. O. Box JB-1331 New Haven, CT 06505	1(800)243-6624
Emed Graphic Communications P. O. Box 369 Buffalo, NY 14240-0369	1(800)442-3633
D & C Sign and Label P. O. Box KA-157 Northford, CT 06472	1(800)356-9269
Brady Sign Mark Division 727 W. Glendale Ave P. O. Box 571 Milwaukee, WI 53201	1(800)635-7557

HMIS®

HEALTH

FLAMMABILITY

REACTIVITY

PERSONAL PROTECTION

© 1981 NPCA Since RC 13014

American Labelmark Co., Chgo. IL 60646

NATIONAL FIRE PROTECTION ASSOCIATION

(NFPA) SYSTEM

HEALTH HAZARD

REACTIVITY

SPECIFIC HAZARD

HEALTH HAZARD—BLUE

4 Materials which on very short exposure could cause death or major residual injury even though prompt medical treatment were given

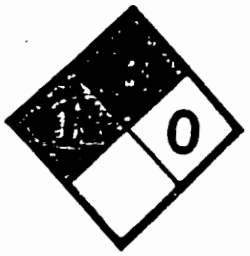
3 Materials which on short exposure could cause serious temporary or residual injury even though prompt medical treatment were given

2 Materials which on intense or continuous exposure could cause temporary incapacitation or possible residual injury unless prompt medical treatment is given

1 Materials which on exposure would cause irritation but only minor residual injury even if no treatment is given

0 Materials which on exposure under fire conditions would offer no hazard beyond that of ordinary combustible material

H-NFWC Printed by LABELMASTER, Chicago, IL 60646 (800) 621-5808



ACETONE

NITRIC ACID

NON-CLASSIFIED WASTE MATERIAL

LABORATORY ANALYSIS IN PROGRESS

CAUTION: THE CONTENTS OF THIS CONTAINER HAVE NOT BEEN CLASSIFIED AND MUST BE MANAGED WITH CAUTION UNTIL CLASSIFIED AND THEN MANAGED ACCORDINGLY. DO NOT OPEN OR MOVE WITHOUT PRIOR APPROVAL FROM GENERATOR/CONTRACTOR. CONTENTS MAY BE HARMFUL TO HUMAN HEALTH OR THE ENVIRONMENT.

MATERIAL: _____

SITE ADDRESS: _____

_____

_____

ACCUMULATION DATE: _____

GENERATOR: _____

GENERATOR CONTACT & PHONE: _____

CONTRACTOR CONTACT & PHONE: _____

_____

_____

NOTE: THIS CONTAINER CANNOT BE SHIPPED UNTIL CLASSIFICATION IS COMPLETE AND CONTAINER IS APPROPRIATELY MARKED AND LABELED IN ACCORDANCE WITH EPA AND D.O.T. REGULATIONS.

NCWM-P

Printed by: Mesa Label Express, 8525 Arjons, Ste. T, San Diego, CA 92126 (619) 693-4988

EXHIBIT B

SOURCES FOR ORDERING

AND

EXAMPLES OF HAZARD AREA WARNING SIGNS

HAZARD COMMUNICATION LABELS

SOURCES FOR ORDERING:

Seton Identification Products P. O. Box JB-1331 New Haven, CT 06505	1(800)243-6624
Emed Graphic Communications P. O. Box 369 Buffalo, NY 14240-0369	1(800)442-3633
D & C Sign and Label P. O. Box KA-157 Northford, CT 06472	1(800)356-9269
Brady Sign Mark Division 727 W. Glendale Ave P. O. Box 571 Milwaukee, WI 53201	1(800)635-7557

GRAPHIC OSHA SIGNS

- Choice of Semi-Rigid or Metal Backed Plastic Signs
- Designed to Meet Proposed ANSI Z535 Specifications

Promote safety with easy to understand wording and eye catching graphics.

373-G

387-G

285-G

381-G

389-G

1200-G

284-G

286-G

335-G

336-G

288-G

375-G

372-G

281-G

388-G

155-G

154-G

290-G

376-G

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392-G

380-G

151-G

391-G

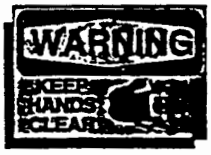
386-G

173-G

337-G

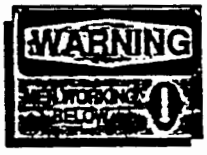
292-G

480-G



481-G

475-G

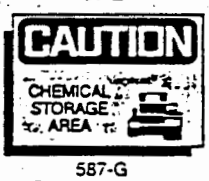


476-G

482-G

478-G

707-G



587-G

579-G

585-G

593-G

580-G

592-G

GRAPHIC OSHA SIGNS

TO ORDER: Specify Style Number, Size, Material and Quantity.
PRICE: Per Sign. OK to assort for best price.

MATERIAL	10"x 7"			14"x 10"		
	1-5	6-11	12 & Up	1-5	6-11	12 & Up
Semi-Rigid Plastic (BSR)	$10.90	$9.60	$8.45	$15.65	$13.60	$11.40
Metal-Backed Plastic (BMB)	13.60	11.30	9.70	20.55	18.30	14.50
Pressure Sensitive Vinyl	8.25	7.50	6.75	9.90	8.75	8.05

EXHIBIT C

REQUEST FOR MISSING MSDS SHEETS LETTER

AND

EXAMPLES OF MATERIAL SAFETY DATA SHEETS

Name of Manufacturer
Address

Dear Technical Information Representative:

This letter is written to request information concerning the potential safety and health hazards from using your product, _____. Please provide me with a Material Safety Data Sheet (MSDS) for your product.

The following specific information is requested for the purpose of fully evaluating the health risk to the employees at our facility who use your product:

1. The identity of any chemical component which may present a health hazard when skin contact, inhalation, or ingestion occurs.

2. The identity of any component which may cause an allergic sensitization.

3. The concentration and identity of any component which is a recognized or suspected carcinogen or reproductive toxin.

4. The concentration of any lead compounds.

Please contact me at _____ should you need this request clarified. Thank you for your assistance on this most important matter.

Sincerely,

Name
Title

Material Safety Data Sheet

May be used to comply with OSHA's Hazard Communication Standard, 29 CFR 1910.1200. Standard must be consulted for specific requirements.

U.S. Department of Labor
Occupational Safety and Health Administration
(Non-Mandatory Form)
Form Approved
OMB No. 1218-0072

IDENTITY *(As Used on Label and List)*

Note: Blank spaces are not permitted. If any item is not applicable, or no information is available, the space must be marked to indicate that.

Section I

Manufacturer's Name	Emergency Telephone Number
Address *(Number, Street, City, State, and ZIP Code)*	Telephone Number for Information
	Date Prepared
	Signature of Preparer *(optional)*

Section II — Hazardous Ingredients/Identity Information

Hazardous Components (Specific Chemical Identity; Common Name(s))	OSHA PEL	ACGIH TLV	Other Limits Recommended	% *(optional)*

Section III — Physical/Chemical Characteristics

Boiling Point		Specific Gravity (H_2O = 1)	
Vapor Pressure (mm Hg.)		Melting Point	
Vapor Density (AIR = 1)		Evaporation Rate (Butyl Acetate = 1)	

Solubility in Water

Appearance and Odor

Section IV — Fire and Explosion Hazard Data

Flash Point (Method Used)	Flammable Limits	LEL	UEL

Extinguishing Media

Special Fire Fighting Procedures

Unusual Fire and Explosion Hazards

printed on recycled paper

Section V — Reactivity Data

Stability	Unstable		Conditions to Avoid
	Stable		

Incompatibility (*Materials to Avoid*)

Hazardous Decomposition or Byproducts

Hazardous Polymerization	May Occur		Conditions to Avoid
	Will Not Occur		

Section VI — Health Hazard Data

Route(s) of Entry: Inhalation? Skin? Ingestion?

Health Hazards (*Acute and Chronic*)

Carcinogenicity: NTP? IARC Monographs? OSHA Regulated?

Signs and Symptoms of Exposure

Medical Conditions
Generally Aggravated by Exposure

Emergency and First Aid Procedures

Section VII — Precautions for Safe Handling and Use

Steps to Be Taken in Case Material Is Released or Spilled

Waste Disposal Method

Precautions to Be Taken in Handling and Storing

Other Precautions

Section VIII — Control Measures

Respiratory Protection (*Specify Type*)

Ventilation	Local Exhaust	Special
	Mechanical (*General*)	Other

Protective Gloves	Eye Protection

Other Protective Clothing or Equipment

Work/Hygienic Practices

* USGPO 1986-491-529/45775

Material Safety Data Sheet

From Genium's Reference Collection
Genium Publishing Corporation
1145 Catalyn Street
Schenectady, NY 12303-1836 USA
(518) 377-8855

GENIUM PUBLISHING CORP.

No. 52

HYDROGEN SULFIDE
(Revision A)
Issued: July 1979
Revised: April 1988

SECTION 1. MATERIAL IDENTIFICATION

Material Name: HYDROGEN SULFIDE

Description (Origin/Uses): Used as a reagent in analytical chemistry and in metallurgy; used to make heavy water.

Other Designations: Sulfureted Hydrogen; H_2S; NIOSH *RTECS* No. MX1225000; CAS No. 7783-06-4

Manufacturer: Contact your supplier or distributor. Consult the latest edition of the *Chemicalweek Buyers' Guide* (Genium ref. 73) for a list of suppliers.

HMIS			
H	4		
F	4	R	1
R	3	I	3
PPG*		S	2
*See sect. 8		K	4

SECTION 2. INGREDIENTS AND HAZARDS

	%	EXPOSURE LIMITS
Hydrogen Sulfide, CAS No. 7783-06-4	*	IDLH** Level: 300 ppm **OSHA PEL** Ceiling:*** 20 ppm **ACGIH TLVs, 1987-88** TLV-TWA: 10 ppm, 14 mg/m³ TLV-STEL: 15 ppm, 21 mg/m³ **NIOSH REL** 10-Min Ceiling: 10 ppm, 15 mg/m³ **Toxicity Data**** Human, Inhalation, LC_{Lo}: 600 ppm (30 Mins)

*Contact your supplier to determine the exact composition of this gas and if any contaminants are present.
**Immediately dangerous to life and health.
***OSHA sets the maximum peak above ceiling PEL as 50 ppm only in an 8-hour shift with no other measurable exposures.
****See NIOSH, *RTECS*, for additional data.

SECTION 3. PHYSICAL DATA

Boiling Point: -76°F (-60°C)
Melting Point: -117°F (-83°C)
Vapor Density: 1.2
Vapor Pressure: >760 Torrs (Normal Atmospheric Pressure)

Water Solubility (%): At 68°F (20°C), 1 gram of H_2S dissolves in 242 ml of water.
Molecular Weight: 34 Grams/Mole

Appearance and Odor: A colorless gas; odor of rotten eggs. **Warning:** Paralysis of olfactory sense occurs at 200 ppm.

SECTION 4. FIRE AND EXPLOSION DATA

Flash Point and Method	Autoignition Temperature	Flammability Limits in Air	LOWER	UPPER
Not Applicable	500°F (260°C)	% by Volume	4.3	46

Extinguishing Media: Hydrogen sulfide gas is a severe fire and explosion hazard; treat any fire involving it as an emergency. Try to shut off the gas; use a water spray to protect personnel attempting this. **Unusual Fire or Explosion Hazards; Danger:** Fire-exposed cylinders containing hydrogen sulfide gas can rupture violently. If it is safe to do so, remove them from the fire area or try to cool them with a direct water spray. This gas is denser than air and can travel a considerable distance to a low-lying source of ignition and flash back. It is flammable or explosive over a wide range of gas/air mixtures (see LEL and UEL). **Special Fire-fighting Procedures:** Wear a self-contained breathing apparatus (SCBA) with a full facepiece operated in the pressure-demand or positive-pressure mode. Fire fighters must use the maximum personal protective equipment available. Fight fires from explosion-proof or unmanned locations.

SECTION 5. REACTIVITY DATA

Hydrogen sulfide is stable in closed, airtight, pressurized containers at room temperature under normal storage and handling conditions. It does not undergo hazardous polymerization.

Chemical Incompatibilities: This material is very reactive; hazardous reactions occur between it and strong oxidizing agents, nitric acid, soda lime, sodium, sodium peroxide, acetaldehyde, copper, and others (see Genium ref. 84, p. 491M-107).

Conditions to Avoid: Do not allow sources of ignition such as open flame, unprotected heaters, lighted tobacco products, electric sparks, or excessive heat in work areas because of the extreme flammability of hydrogen sulfide.

Hazardous Products of Decomposition: During fires hydrogen sulfide may produce toxic gases such as sulfur oxides (SO_x).

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SECTION 6. HEALTH HAZARD INFORMATION

Hydrogen sulfide is not listed as a carcinogen by the NTP, IARC, or OSHA.

Summary of Risks: High concentrations (500-1000 ppm) of this material can cause systemic poisoning symptomized by respiratory paralysis, and unconsciousness, followed by death. Exposures of 50 to 500 ppm are characterized by respiratory irritation (coughing, difficulty in breathing). Eye and upper respiratory tract (URT) irritation start around 20 ppm; the severity increases with the duration and intensity of exposure. The sense of smell can be paralyzed immediately by exposure to 200 ppm. Collapse quickly followed by coma and possibly death can occur after breathing only a small amount at >1000 ppm.

Medical Conditions Aggravated by Long-Term Exposure: None reported. **Target Organs:** Eyes, respiratory system.

Primary Entry: Skin contact, inhalation. **Acute Effects:** Eye and URT irritation, dizziness, headache, and nausea.

Chronic Effects: None reported.

FIRST AID

Eyes: Immediately flush eyes, including under the eyelids, gently but thoroughly with plenty of running water for at least 15 minutes.

Skin: Treat for possible frostbite damage (cryogenic injury) if liquid hydrogen sulfide touches skin. Treat also for corrosive, acidic burns from either the gas or liquid. **Inhalation:** Remove the exposed person to fresh air; restore and/or support his or her breathing as needed. Rescuers must use good judgment to minimize their own personal risk. **Ingestion:** Unlikely.

GET MEDICAL HELP (IN PLANT, PARAMEDIC, COMMUNITY) FOR ALL EXPOSURES. Seek prompt medical assistance for further treatment, observation, and support after first aid.

SECTION 7. SPILL, LEAK, AND DISPOSAL PROCEDURES

Spill/Leak: *Treat any hydrogen sulfide gas leak as an emergency.* Preplan for gas leaks and make these preparations known to all relevant personnel. Notify safety personnel, evacuate all nonessential personnel, provide maximum explosion-proof ventilation, and eliminate all sources of ignition immediately. Try to stop the flow of gas; use a water spray to protect personnel attempting to do this. Cleanup personnel require a complete set of protective clothing, including an SCBA.

Waste Disposal: Contact your supplier or a licensed contractor for detailed recommendations. Follow Federal, state, and local regulations.

OSHA Designations

Air Contaminant (29 CFR 1910.1000 Subpart Z)

EPA Designations (40 CFR 302.4)

RCRA Hazardous Waste, No. U135

CERCLA Hazardous Substance, Reportable Quantity: 100 lbs (45.4 kg)

SECTION 8. SPECIAL PROTECTION INFORMATION

Goggles: Always wear protective eyeglasses or chemical safety goggles. Follow the eye- and face-protection guidelines in 29 CFR 1910.133. **Respirator:** Wear a NIOSH-approved respirator per the *NIOSH Pocket Guide to Chemical Hazards* for the maximum-use concentrations and/or the exposure limits cited in section 2. Follow the respirator guidelines in 29 CFR 1910.134. For emergency or nonroutine use (e.g., cleaning reactor vessels or storage tanks), wear an SCBA with a full facepiece operated in the pressure-demand or positive-pressure mode. **Warning:** Air-purifying respirators will *not* protect workers in oxygen-deficient atmospheres.

Other: Wear impervious gloves; boots; aprons; and clean, impervious, body-covering clothing to prevent any possibility of hydrogen sulfide's contact with skin. All clothing must be flame resistant. **Ventilation:** Install and operate general and local ventilation systems powerful enough to maintain airborne levels of hydrogen sulfide below the exposure limit cited in section 2. Make all ventilation systems of maximum explosion-proof design (e.g., nonsparking, electrically grounded and bonded, etc.)

Safety Stations: Make eyewash stations, washing facilities, and safety showers available in use and handling areas.

Contaminated Equipment: Contact lenses pose a special hazard; soft lenses may absorb irritants and all lenses concentrate them. Do *not* wear contact lenses in any work area. **Other:** All piping and equipment used with this gas must be pressure checked and leak tight.

Comments: Practice good personal hygiene; always wash thoroughly after using this material. Avoid transferring it from your hands to your mouth while eating, drinking, or smoking. Do *not* eat, drink, or smoke in any work area.

SECTION 9. SPECIAL PRECAUTIONS AND COMMENTS

Storage/Segregation: Store hydrogen sulfide in a cool, dry, well-ventilated area away from oxidizing agents, sources of heat or ignition, any flammable/explosive materials, cylinders containing oxygen, and incompatible chemicals (see sect. 5). Use outside or detached storage. Store cylinders upright and secure them tightly. **Special Handling/Storage:** Hydrogen sulfide is shipped and stored as a pressurized gas in cylinders or tank cars. Protect them against physical damage and regularly inspect them for cracks, leaks, or faulty valves. Electrically ground and bond all containers used in shipping or transferring operations to prevent static sparks. Do not drag or slide cylinders; move them in a carefully supervised manner with a suitable hand truck. Do not smoke in any use or storage area. Shade containers from radiant heat and direct sunlight. **Engineering Controls:** Make all engineering systems (ventilation, production, etc.) of maximum explosion-proof design. Hydrogen sulfide must be used in closed engineering systems because of its explosibility (see sect. 4). Evacuate and purge all lines with an inert gas such as nitrogen (N_2) before and after using hydrogen sulfide. **Comments:** Perform all operations with hydrogen sulfide carefully to prevent accidental ignition. Keep the valve-protection cap in place until immediately before use. Insert a check valve or trap into the transferral line to prevent a dangerous backflow into the original container. Use pressure-reducing regulators when connecting a cylinder to a lower-pressure piping system. Obtain detailed handling, shipping, and storage information from your supplier. A trained chemist or safety specialist familiar with the physical and chemical properties of this material should be present during all work operations.

Transportation Data (49 CFR 172.101-2)

DOT Shipping Name: Hydrogen Sulfide	DOT Label: Flammable Gas and Poison	IMO Class: 2.1
DOT ID No. UN1053	DOT CLass: Flammable Gas	IMO Label: Flammable Gas and Poison Gas

References: 1, 2, 12, 73, 84-94, 100, 103.

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Prepared by PJ Igoe, BS

Industrial Hygiene Review: DJ Wilson, CIH

Medical Review: MJ Hardies, MD

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WORKPLACE ENVIRONMENTAL EXPOSURE LEVEL GUIDE

AMERICAN INDUSTRIAL HYGIENE ASSOCIATION

METHYL TERT-BUTYL ETHER

(1991)

I. IDENTIFICATION

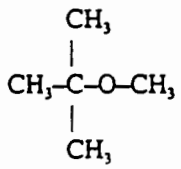
Chemical Name: Methyl tert-butyl ether

Synonyms: 2-methoxy-2-methyl-propane; tert-butyl methyl ether; MTBE; 2,2-MMOP

CAS Number: 1634-04-4

Molecular Formula: $C_5H_{12}O$

Structural Formula:



II. CHEMICAL AND PHYSICAL PROPERTIES[1,2]

Physical State: Colorless liquid

Molecular Weight: 88.15

Conversion Factor: 1 ppm = 3.61 mg/m^3; 1 mg/m^3 = 0.28 ppm at 25°C

Boiling Point: 55°C (131°F) at 760 mmHg

Melting Point: –109°C (–164°F)

Vapor Pressure: 245 mmHg at 25°C (77°F)

Saturated Vapor Concentration: 322 000 ppm at 25°C (77°F)

Odor Description: Slight terpene-like odor

Odor Threshold: 0.6 ppm

Flammability Limits: Lower explosive limit: 2.5%; upper explosive limit: 15.1%

Flash Point: –10°C (–14°F) (closed-cup)

Autoignition Temperature: 224°C (435°F)

Specific Gravity: 0.74 at 20°C (68°F)

Vapor Density: 3.1 (air = 1)

Solubility in Water: 4.8% at 25°C (77°F)

Stability: Unstable in acid solutions

Reactivity and Incompatibilities: May react with air to form unstable peroxide; incompatible with strong acids, bases, and oxidizers

III. USES AND VOLUME

MTBE is used as an octane booster in gasoline. The 1981 production of MTBE was 3.45×10^8 kg.[3]

IV. TOXICOLOGY DATA

A. Acute Toxicity

1. *Oral Toxicity*

Rat: LD_{50} 2.8 g/kg[4]

2. *Eye Toxicity*

Rabbit: 0.1 mL of undiluted MTBE instilled into the conjunctival sac of the eye produced mild irritation[4]

3. *Skin Toxicity*

a. Irritation

Rabbit: minimally irritating(5)

b. Absorption

Rabbit: LD_{50} >10.2 g/kg(4)

4. *Inhalation*

Rat: 4-hr LC_{50} 23 546 ppm[4]

Mouse: 15-min LC_{50} 39 070 ppm[1]

A single 6-hr exposure of rats to MTBE resulted in several functional observation battery findings in the 8000 ppm exposure group and occasional findings in the 4000 ppm exposure group. Clear motor activity changes were observed in the 8000 ppm exposure group. The pattern and time course of effects were indicative of transient central nervous system (CNS) sedation. In contrast to the effects observed in the 8000 ppm group, transient increases in motor activity were observed for males in the 800 and 4000 ppm exposure groups. The biological significance of the increase in activity was unclear but might reflect an exposure-related stimulant effect or an exaggerated response following recovery from possible anesthetic effect.[6]

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Two Rhesus monkeys were exposed 6 hr/day for 5 days to progressively higher concentrations of MTBE. No adverse effects were noted until after 65 min of the third exposure period (8500 ppm), at which time both monkeys became ataxic. On the fourth exposure, the female monkey was unconscious after 58 min of exposure (18 000 ppm), and the male monkey was unconscious after 50 min of exposure (31 000 ppm). On the last exposure, the female monkey was unconscious after 43 min of exposure to 49 000 ppm, and the male monkey was unconscious after 24 min of exposure to 95 500 ppm.[7]

B. Genotoxicity

MTBE was not mutagenic when tested in *Salmonella* and *Saccharomyces* or in tests for sister chromatid exchange and chromosomal aberrations in Chinese hamster ovary cells.[8] MTBE was mutagenic in the L5178Y mouse lymphoma assay only in the presence of an S-9 metabolic activation system.[8] It was surmised that a metabolite, possibly formaldehyde rather than MTBE itself, was the mutagenic agent. MTBE was not mutagenic in the *Drosophila melanogaster* sex-linked recessive lethal test.[9] Rats exposed to 800, 4000, and 8000 ppm MTBE 6 hr/day for 5 days did not exhibit any significant increase in the incidence of chromosomal aberrations in the bone marrow cells.[10]

C. Metabolism and Pharmacokinetics

[^{14}C]-MTBE (7.3 or 14.6 mg/kg) injected intraperitoneally (i.p.) to rats was excreted rapidly in expired air (65%–79% in 24 hr). Small amounts were recovered in the urine (3%–5%) and feces (0.5%–1.5%) 48 hr following administration. About 8%–16% remained in the body 96 hr after treatment.[11] In another study, rats injected i.p. with 230 mg/kg [^{14}C]-MTBE eliminated 92% of the dose in the expired air within 6 hr. About 1% and 3% of the dose was found in the feces and urine, respectively. Analysis indicated that the majority of the fecal and urinary metabolite was formic acid.[12] Another study also reported that expired air was the major route of excretion in rats given a single intravenous injection (10 or 40 mg/kg) of MTBE.[13] The pharmacokinetics of MTBE following a single oral dose (40 mg/kg) was also investigated. The oral bioavailability of MTBE was determined to be about 37%.[13] The pharmacokinetics of [^{14}C]-MTBE (58 mg/kg) administered i.p. to monkeys was similar to that in rats. The monkey excreted MTBE rapidly in expired air (68% within 8 hr). About 5% appeared in the urine with <0.5% excreted via feces. About 7% was retained in the body 96 hr following treatment. Total recoveries of 82%–85% were reported.[14]

D. Reproductive Development

Male rats exposed to 250, 1000, and 2500 ppm MTBE 6 hr/day, 5 days/week, for a 12-week period were mated to female rats exposed to the same concentrations for a 3-week period. Exposures continued through the mating period, and exposure continued for females during gestation and from Days 5 through 21 of the lactation period. The litters were not exposed. No adverse effects were seen in the treated adult animals and the pups.[15]

Mated rats and mice were exposed during the period of organogenesis to 250, 1000, and 2500 ppm MTBE. No teratogenic effect was observed in the rat. No significant effects were observed in any groups of treated mice on external and soft-tissue examination or evaluation of skeletal abnormalities or ossification variations. The incidence of fused sternabrae in the high-concentration group increased slightly, which might be attributed to fetotoxicity.[16]

Mice were exposed to 1000, 4000, and 8000 ppm MTBE 6 hr/day on Days 8 through 15 of pregnancy. Maternal toxicity (significant reduction in body weight and clinical signs of toxicity) and developmental toxicity (decreased number of viable implantations, reduced fetal body weights) were observed at 4000 and 8000 ppm. There was a significant increase in the incidence of cleft palate at 8000 ppm. The no observed effect level for both maternal toxicity and developmental toxicity was 1000 ppm.[17]

Rabbits were exposed to 1000, 4000, and 8000 ppm MTBE 6 hr/day on Days 6 through 18 of gestation. Maternal toxicity was observed at 4000 and 8000 ppm (significant reduction in weight gain and food consumption at 4000 and 8000 ppm and in increase in relative liver weight at 8000 ppm). Gestational parameters, including number of implantation sites and fetal body weights, exhibited no significant changes. There were no significant changes in the incidence of malformations.[18]

E. Subacute Toxicity

Rats were exposed to 100, 300, 1000, or 3000 ppm MTBE 6 hr/day, 5 days/week, for 9 exposures. Lacrimation, conjunctival swelling, and corneal changes were seen in rats exposed to 1000 and 3000 ppm. A reduced reaction to auditory stimuli at 3000 ppm was noted. There were no other macroscopic pathology findings other than chronic inflammatory changes in the nasal mucosa and trachea at the 1000 and 3000 ppm exposure levels.[19]

No adverse effects were noted in rats[20] and monkeys[21] exposed to 2000 and 3000 ppm MTBE 6 hr/day, 5 days/week, for 2 weeks.

F. Subchronic Toxicity

Rats were exposed to 50, 100 or 300 ppm MTBE 6 hr/day, 5 days/week, for 2 to 15 weeks. Exposures caused a transient increase in UDP-glucuronosyltransferase activities in liver and kidney microsomes but no other changes.[22]

No adverse effects were seen in rats exposed to 250, 500, and 1000 ppm MTBE 6 hr/day, 5 days/week for 13 weeks.[23]

Rats were exposed to 800, 4000, or 8000 ppm MTBE 6 hr/day, 5 days/week, for 13 weeks. Statistically significant increases in the mean absolute and relative weights of the liver, kidneys, and adrenal gland were noted in rats exposed to 4000 and 8000 ppm. Mild hematologic changes (less than 5%) were also observed in all the exposed animals. These alterations were not judged to be significant since the changes were minor and not dependent on concentration. There were no other treatment-related lesions or microscopic changes.[24]

G. Chronic Toxicity and Carcinogenicity

No data are currently available. The MTBE Task Force of the Oxygenated Fuels Association is conducting an oncogenicity study under the Environmental Protection Agency Toxic Substance Control Act Section 4, Testing Consent Agreement. Results of this study will be available in November 1992.

V. HUMAN USE AND EXPERIENCE

Industrial hygiene monitoring data reported by a user company indicated airborne concentrations were generally below 5 ppm under normal operating conditions, which included loading/unloading gasoline trucks and performing maintenance work near sources of MTBE.[25]

Another company reported results of industrial hygiene monitoring conducted at an MTBE manufacturing plant, a marketing terminal, three refineries, and two marine barges loading and transporting blended gasoline. The mean concentrations of MTBE at the manufacturing plant and the marketing terminal were below 2 ppm. At the refineries and the marine barges, the mean full-shift personnel exposures were less than 31 ppm and 15 ppm, respectively.[26]

VI. RATIONALE

MTBE has low acute toxicity and is mildly irritating to the eyes and skin. Results from several developmental toxicity studies in mice, rats, and rabbits suggest that the no observed effect level (NOEL) is about 1000 to 2500 ppm. The weight of evidence from subacute and subchronic inhalation studies in rats and monkeys indicate that the NOEL is 800 ppm or higher. A workplace environmental exposure level (WEEL) guide of 100 ppm for an 8-hr time-weighted average (TWA) is recommended [illegible] repeated exposure.

VII. RECOMMENDED WEEL GUIDE

8-hr TWA: 100 ppm (360 mg/m^3)

VIII. REFERENCES

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EXHIBIT D

EXAMPLE OF CHEMICAL INVENTORY SHEETS FOR A WAREHOUSE

NORWOOD WAREHOUSE MSDS COLLECTION
HAZ COMM/RTG PROGRAM
INDEX

Product Name	Manufacturer
ACETIC ACID	AXTON CROSS
	LIQUID-CARBONIC
ALCONOX	ALCONOX
ANTIFOAM	BIOLAB INC.
ANTIFORM, 1410	ASHLAND CHEMICAL
ANTIFREEZE	PIONEER OIL COMPANY
BENTONITE, ENVIROPLUG, COARSE	WYO-BEN
BENTONITE, ENVIROPLUG, MED	WYO-BEN
BENTONITE, ENVIROPLUG, FINE	WYO-BEN
CARBON, ACTIVATED	ATO-CHEM.
CARBON, ACTIVATED	CALGON
CAUSTIC SODA, FLAKES	OCCIDENTAL CHEMICAL
CAUSTIC SODA, LIQUID	LCP CHEMICALS
CHICO	CROUSE HINDS
CHLORINE PELLETS	AUTOTROL
CONCRETE MIX	AMERICAN STONE-MIX INC.
DEGREASER	ENVIRONMENTAL TECHNILOGIES
DEGREASER, HEAVY DUTY	THE HOTSY CORPORATION
DICHLOROETHANE	SUPELCO INC.
DICHLOROETHYLENE	SUPELCO INC.
DI-N-OCTYL-PHTHALATE	SUPELCO INC.
DIOCTYL PHTHALATE, 99%	ALDRISH CHEMICAL
DISINFECTANT DETERGENT	DECON LABS
EPOXY-POLYAMIDE COATING	DAMPNEY COMPANY
ERTHORBIC ACID	PFIZER CHEMICAL
EYEWASH SOLUTION	FENDALL COMPANY

Product Name	Manufacturer
GAS, COMPRESSED AIR (21% O_2/79%N)	MSA
GAS, HEXANE	GAS TECH INC.
GAS, ISOBUTYLENE	LIQUID-CARBONIC
GAS, METHANE	GASTECH INC.
GAS, OXYGEN	BERNZOMATIC CORPORATION
GAS, PROPANE	BERNZOMATIC CORPORATION
GASOLINE, UNLEADED	EXXON COMPANY
GLUE-ALL, ELMERS	BORDON, INC.
GLUE, PVC, WELD-ON	I.P.S.
GLUE, WOOD, ELMERS	BORDON INC.
GRANCONTROL O	C&A PRODUCTS INC.
GROUT	WYO-BEN, INC.
HYDROCHLORIC ACID, 20°	E&F KING
HYDROCHLORIC ACID, 18°, 20°, 22°	BALTIMORE CHEMICAL PLANT
HYDROCHLORIC ACID, 365-38%	J.T. BAKER
HYDROGEN PEROXIDE	E.F. KING
LIQUIDNOX	ALCONOX INC.
METHANOL	EM SCIENCE
METHYLENE CHLORIDE	J.T. BAKER
NITRIC ACID 69-71%	FISHER SCIENTIFIC
N-NITROSO DIPHENYLAMINE	ACCUSTANDARD
NUTRIENT BLEND, E.N.D.	O'NIELL INDUSTRY
NU-WELL, CLEANING COMPOUND	JOHNSON FILTRATION
OIL, MOTOR	SUN REFINING & MARKETING CO.
OIL, LUBRICATING	SHELL OIL COMPANY

Product Name	Manufacturer
PADS, RESPIRATOR WIPES	NORTH SAFETY CO.
PAINT ENAMEL	GLIDEN COATINGS & RESINS
PAINT, LATEX BLUE	BENJAMIN MOORE CO.
PAINT, LATEX, WALL	THE GLIDEN CO.
PAINT, SPRAY, MARKETING, ORANGE	LAWSON PRODUCTS
PAINT, SPRAY	MARTIN-SEMOUR CO.
PAINT, SPRAY, KRYLOW	BORDEN INC.
PAINT THINNER	DAMPNEY CO.
PENETONE 58	PENETONE CO.
POLY TREAT "A"	LEA
POLYNUCLEOLYTE	ENSOTECH INC.
POLYPROPYLENE PLASTIC	NORTON CO.
PRIMER, PVC, WELD-ON	I.P.S. CORPORATION
RAID INSPECT KILLER	S.C. JOHNSON & SON
SAND, JESSE MORIE	THE MORIE CO.
SEALER, RADIATOR	RADIATOR SPECIALTY CO.
SILICONE SPRAY	FIRST BRANDS
SOLUTION, PN 4	ANALTICAL MEASUREMENTS
SOLUTION PN7	ANALITICAL MEASUREMENTS
SOAP, ANTIMICROBIAL	D-CON
SOAP, SOFT-SUDS	TURBO-TECK ENTERPRISES
SODIUM ACID PYROPHOSPHATE	MONSANTO
SODIUM CHLORIDE	HACH CO.
SODIUM HEXAMETA PHOSPHATE	GEORGE MANN & CO.
SODIUM HYDROXIDE, 25%	E&F KING
SODIUM HYDROXIDE, 50%	E&F KING
SODIUM THIOSULFATE CRYSTALS	E&M SCIENCE
STAIN, CUPRINOL, WOOD, PERSU.	DARWORTH CO.
TETRACHLOROETHYLENE	EASTMAN KODAK CO.
TRICHLOROETHANE	FISHER SCIENTIFIC

EXHIBIT E

EXAMPLES OF HAZARD COMMUNICATION DOCUMENTATION SHEETS

GROUNDWATER TECHNOLOGY
TRAINING DOCUMENT

Name_____Date_____

SS#_____-_____-_____Emp.#_____Job Title_____

Training/Seminar Title: Hazard Communication Training_____Code:_____

Training Description_____

_____

Training Sponsor Agency:_____

Length of training session_____(Hours)

I certify that I have been trained in the above subject matter and have had the opportunity to ask questions and that those questions have been answered to my satisfaction.

_____
Employee Signature

_____
Instructor Signature

*Please forward a readable copy of this document along with a copy of the **Training Course Log** to:*

Corporate Health & Safety Training
Groundwater Technology
100 River Ridge Drive
Norwood, MA 02062

GROUNDWATER TECHNOLOGY, INC.
HAZARD COMMUNICATION PROGRAM PART I
EMPLOYEE TRAINING

Employee Name:_____ Date:_____

Job Title:_____ SSN #: _____

Location: _____ Region:_____

I have received instruction in the following topics as part of my Groundwater Technology, Inc. Hazard Communication Training Program.

Employee Signature_____ Date_____

Instructor Signature_____ Date_____

General Program Topics:

1. Elements of the OSHA Hazard Communication Standard.

2. Elements of Groundwater Technology, Inc. written Hazard Communication Program.

3. Review of the Chemical Inventory for this work site.

4. Review of the MSDS sheets for hazardous chemicals located at this work site, and identify the location for copies of these MSDS sheets.

5. Discussed the Company work processes with potential risks for exposure that utilize hazardous chemicals, and explain action of proper standard operating procedures to be used in each process.

6. Discussed the potential environmental and personal risks for an accidental release or spill of hazardous chemical, the emergency procedures to be followed and protection to wear in the event of a spill.

7. Review of contingency and evacuation plans for fires, medical emergencies or other emergency incidents.

8. Explanation of health risks associated with hazardous chemicals and discuss the routes of entry into the body.

9. Discussed the warning signs and symptoms of exposure to hazardous chemicals.

10. Outlines of the physical, biological and chemical hazards present at the work site, and the proper personal protective equipment to wear for minimizing these hazard risks.

11. Explanation of other environmental risks on site such as noise, heat, cold, or lighting and procedures or guidelines to minimize these hazards.

12. Show the hazard labels and signs utilized at the work site for identification of hazardous materials or hazardous areas.

GROUNDWATER TECHNOLOGY, INC.
HAZARD COMMUNICATION PROGRAM Part II: Site Specific Program
EMPLOYEE TRAINING

Employee Name:_____ Date:_____

Job Title:_____SSN #: _____

Location: _____ Region:_____

I have received instruction in the following topics as Part II of the GT Hazard Communication Program and completion of the 29 CFR 1910.120- standard training requirement: (3 days on site training)

a. Review of MSDS for each potential chemical hazard on site.

b. Review of specific work practices and personal protective equipment required to protect employees from potential hazards on site.

c. Explanation of emergency procedures for spills, leaks, fires, medical emergencies, vapor releases, confined space problems, etc.

d. Review of proper methods of personal protective equipment selection and use.

e. Explanation of possible environmental risks to site personnel such as heat, cold, noise, and lighting.

Site Specific Safety Orientation Training:

Description:
_____
_____
_____
_____

Employee signature:_____Date:_____

Supervisor's Name:_____Hours of Training:_____

EXHIBIT F

EXAMPLES OF ELECTRICAL SAFETY LABELING

LOCKOUT/TAGOUT LABELING

AND

SOURCES OF LABELS

HAZARD COMMUNICATION LABELS

SOURCES FOR ORDERING:

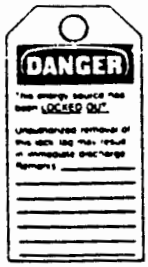
Seton Identification Products P. O. Box JB-1331 New Haven, CT 06505	1(800)243-6624
Emed Graphic Communications P. O. Box 369 Buffalo, NY 14240-0369	1(800)442-3633
D & C Sign and Label P. O. Box KA-157 Northford, CT 06472	1(800)356-9269
Brady Sign Mark Division 727 W. Glendale Ave P. O. Box 571 Milwaukee, WI 53201	1(800)635-7557

Rev. Side #1 - 65502
Rev. Side #2 - 65535
Rev. Side #3 - 65670

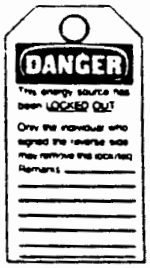
Rev. Side #1 - 65503
Rev. Side #2 - 65521

Rev. Side #1 - 65504
Rev. Side #2 - 65522

Rev. Side #1 - 65505
Rev. Side #2 - 65523



Reverse Side #1



Reverse Side #2

Reverse Side #3

Rev. Side #1 - 65506
Rev. Side #2 - 65534

Rev. Side #1 - 65515
Rev. Side #2 - 65524

Rev. Side #1 - 65520
Rev. Side #2 - 65525
Rev. Side #3 - 65671

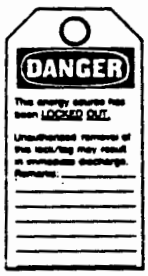
Rev. Side #1 - 65526
Rev. Side #2 - 65527

OSHA requires that all lockout and tagout devices shall indicate the identity of the employee applying the device. Tags are designed for repeated use. Simply assign a set of tags to each employee.

- Brass Grommet for added strength. Large enough to accept most locks (7/16" inside diameter).
- Polyester laminate protects graphics, wipes clean and stands up against water, grease and extreme temperatures.
- Write-on matte finish allows workers to personalize tags with pen, pencil or marker.
- Heavy duty construction prevents accidental removal. Withstands over 80 lbs. of pulling pressure.
- 8" Nylon ties – 50 lbs. unlocking strength (Cat. No. 91166) and permanent Markers (Cat. No. 87052) available for attaching and signing tags.
- Standard Package: 25 identical 5-1/2" x 3" tags.
- Custom tags available, call your local distributor for more information.

Photo Identification Tags

Catalog No. 65500



Reverse Side

Standard Package:
25 – 5-1/4" x 2-3/4" paper tags.
25 – 5-1/2" x 3" overlaminate pouches.
Catalog No. 65500

Heavy Duty Laminated Tags

Photo Identification tags make it easy to identify individuals working on equipment. Photographs can be taken with most photo I.D. cameras. These tags provide long lasting protection. To use, simply sign tag, place photo in designated area, insert tag into overlaminate pouch and run through heat laminator (Catalog No. 23320). Tag has chamfered corners and 7/16" hole.

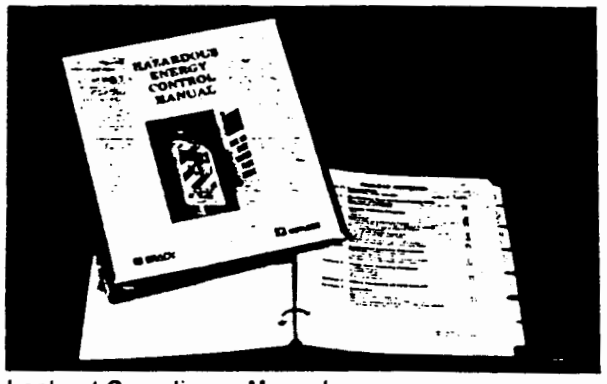
Catalog No. 65501

Reverse Side

Standard Package:
25 identical 5-3/4" x 3" tags.
Catalog No. 65501

Self Sealing Laminated Tags

Make it easy to identify individuals working on equipment. These tags are rigid vinyl with polyester overlaminate. To use, employee signs tag, places photo on tag and applies self-sticking laminate to front of tag. Tag has chamfered corners and heavy-duty 7/16" brass grommet.



Lockout Compliance Manual

This two volume compliance set contains samples that highlight what OSHA is looking for and demonstrates what you must do to comply with lockout/tagout regulations.

Hazardous Energy Control Manual (Volume I)

85 page manual includes:

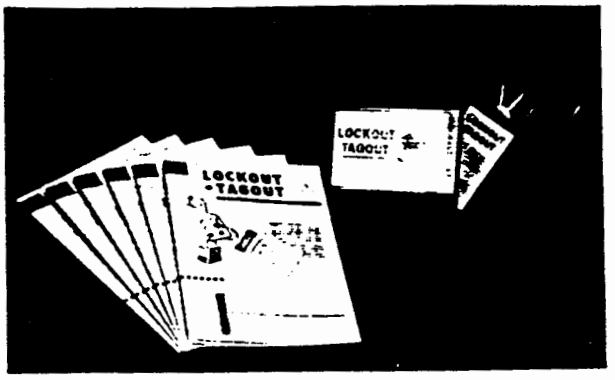
- Step-by-step instructions for developing your lockout/tagout compliance program.
- Suggested training program including outlines, training notes and handout materials.
- Forms and checklists for developing your hazardous energy control procedures.
- Sample programs and procedures.
- Copy of OSHA Standard 29 CFR 1910.147.

Hazardous Energy Control Procedures (Volume II)

Includes sample programs and forms for completing your inventory listing, equipment procedures and employee training log. Three ring binder designed to contain your written program and related information.

Catalog No. 65558
Two Volume Set

Catalog No. 65557
Additional Procedure Binder



Lockout Video and Training Booklets

This two-part program explains OSHA's Lockout/Tagout Standard and details correct procedures for locking and tagging. The video and training booklets are comprehensive and easy-to-understand. They also convincingly demonstrate why following the rules can be a life or death matter.

Part I (The Regulation):

- Hazards of Uncontrolled Energy
- Importance of Lockout/Tagout
- When Should You Lock or Tag?
- Four E's of Safety

Part II (How To Comply):

- Applying Energy Controls
- Equipment Shutdown and Isolation
- Applying Lockout/Tagout Devices
- Control of Stored Energy
- Verification of Isolation

Length: 27 minutes. Spanish version: 66153.

Video Standard Package: 1
Catalog No. 65554

Training Booklets Standard Package: 10 **Catalog No. 65555**

Lockout Signs and Labels

Self-sticking Vinyl (B-946)
65580 – 2-1/4" x 4-1/2"

Self-sticking Vinyl (B-946)
65581 – 2-1/4" x 4-1/2"

Self-sticking Vinyl (B-946)
65582 – 2-1/4" x 4-1/2"

Self-sticking Vinyl (B-946)
65583 – 2-1/4" x 4-1/2"

Fiberglass (B-120)
65516 – 14" x 10"
65517 – 10" x 7"
Self-sticking Vinyl (B-946)
65518 – 10" x 7"
65510 – 7" x 5"
65509 – 5" x 3-1/2"

Fiberglass (B-120)
65575 – 14" x 10"
65576 – 10" x 7"
Self-sticking Vinyl (B-946)
65577 – 10" x 7"
65578 – 7" x 5"
65579 – 5" x 3-1/2"

Self-sticking Vinyl (B-946)
65584 – 2-1/4" x 4-1/2"

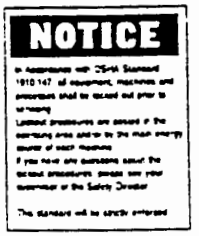
Fiberglass (B-120)
65570 – 14" x 10"
65571 – 10" x 7"
Self-sticking Vinyl (B-946)
65572 – 10" x 7"
65573 – 7" x 5"
65574 – 5" x 3-1/2"

Fiberglass (B-120)
65681 – 14" x 10"
65682 – 10" x 7"
Self-sticking Vinyl (B-946)
65683 – 10" x 7"
65684 – 7" x 5"
65685 – 5" x 3-1/2"

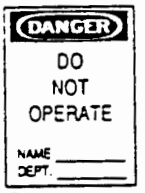
Self-sticking Vinyl (B-826)
65507 – 3/4" x 5"

Clear Overlaminate (B-674)
65508 – 1" x 6"

Brady Lock Labels are an easy way to identify employee's locks. Employees sign the label, attach it to their lock and cover the label with a polyester over-laminate (sold separately).



Fiberglass (B-120)
65511 – 20" x 14"



Self-sticking Vinyl-Cloth (B-500)
65519 – 5" x 3-1/2"

Temporarily tag out equipment not designed to be locked out. This label has a removable adhesive.

WARRANTY

"Brady products are sold with the understanding that the buyer will test them in actual use and determine for himself their adaptability to his intended uses. Brady warrants to the buyer that its products are free from defects in material and workmanship, but limits its obligation under the warranty to replacement of the product shown to Brady's satisfaction to have been defective at the time Brady sold it. This warranty does not extend to any persons obtaining the product from the buyer. THIS WARRANTY IS IN LIEU OF ANY OTHER WARRANTY EXPRESS OR IMPLIED INCLUDING BUT NOT LIMITED TO ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE AND OF ANY OTHER OBLIGATIONS OR LIABILITY ON BRADY'S PART. UNDER NO CIRCUMSTANCES WILL BRADY BE LIABLE FOR ANY LOSS, DAMAGE, EXPENSE OR CONSEQUENTIAL DAMAGES OF ANY KIND ARISING IN CONNECTION WITH THE USE OR INABILITY TO USE BRADY'S PRODUCT."

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EXHIBIT G

HAZARD COMMUNICATION AUDIT FORM

APPENDIX B-2

MSDS LOG

MATERIAL SAFETY DATA SHEETS (MSDS)

Project/Task Name:	**Project/Task Numbers:**
Form Completed By: (print name)	(signature) (date)

In accordance with the OSHA Hazard Communication Standards (1910.1200 and 1926.59) a MSDS must be readily accessible on-site for each hazardous chemical. This applies to all "chemicals" brought on-site such as bentonite clay, calibration gases, cleaning agents, epoxy, PVC pipe cleaner and cement, sample preservatives, and welding rods. **This requirement does not apply to hazardous wastes.** Material Safety Data Sheets for the chemicals listed below are to be included as a part of this appendix to the SSHP or maintained in a separate file or binder on-site. This form/list is to be updated whenever new chemicals are introduced.

Product or Chemical Name (list):	**Manufacturer or Distributor** (list):	**Date** (listed):

APPENDIX B-3

MSDS DEFINITIONS

MSDS DEFINITIONS

article. A manufactured item exempt from the OSHA Hazard Communication Standard: (i) Which is formed to a specific shape or design during manufacture; (ii) which has end use function(s) dependent in whole or in part upon its shape or design during end use; and (iii) which does not release, or otherwise result in exposure to, a hazardous chemical, under normal conditions of use.

chemical. Any element, chemical compound or mixture of elements, and/or compounds.

chemical manufacturer. An employer with a workplace where chemical(s) are produced for use or distribution.

chemical name. The scientific designation of a chemical in accordance with the nomenclature system developed by the International Union of Pure and Applied Chemistry (IUPAC) or the Chemical Abstracts Service (CAS) rules of nomenclature, or a name which will clearly identify the chemical for the purpose of conducting a hazard evaluation.

combustible liquid. A liquid having a flashpoint at or above 100°F (37.8°C), but below 200°F (93.3°C).

common name. Any designation or identification such as code name, code number, trade name, brand name, or generic name used to identify a chemical other than by its chemical name.

compressed gas. (i) A gas or mixture of gases having, in a container, an absolute pressure exceeding 40 psi at 70°F (21.1°C); or (ii) A gas or mixture of gases having, in a container, an absolute pressure exceeding 104 psi at 130°F (54.4°C) regardless of the pressure at 70°F (21.1°C); or (iii) A liquid having a vapor pressure exceeding 40 psi at 100°F (37.8°C) as determined by ASTM D-323-72.

container. Any bag, barrel, bottle, box, can, cylinder, drum, reaction vessel, storage tank, or the like that contains a hazardous chemical. For Hazard Communication purposes, pipes, or piping systems, and engines, fuel tanks, or other operating systems in a vehicle, are not considered to be containers.

distributor. A business, other than a chemical manufacturer or importer, which supplies hazardous chemicals to other distributors or to employers.

employee. A worker who may be exposed to hazardous chemicals under normal operating conditions or in foreseeable emergencies. Workers such as office workers or bank tellers who encounter hazardous chemicals only in non-routine, isolated instances are not covered by the Hazard Communication Standard.

explosive. A chemical that causes a sudden, almost instantaneous release of pressure, gas, and heat when subjected to sudden shock, pressure, or high temperature.

exposed. Exposed means that an employee is subjected to a hazardous chemical in the course of employment through any route of entry (inhalation, ingestion, skin contact, or absorption, etc.), and includes potential (e.g., accidental or possible) exposure.

flammable liquid. Any liquid having a flashpoint below 100°F (37.8°C).

flashpoint. The minimum or lowest temperature at which a liquid gives off a vapor in sufficient concentration just above the liquid surface to ignite.

foreseeable emergency. Any potential occurrence such as, but not limited to, equipment failure, rupture of containers, or failure of control equipment which could result in an uncontrolled release of a hazardous chemical into the workplace.

hazardous chemical. Any chemical which is a physical hazard or a health hazard, as defined by the Hazard Communication Standard, except for: (i) any hazardous waste (as defined by the U.S. EPA); (ii) tobacco or tobacco products; (iii) wood or wood

products; (iv) articles; (v) food, drugs, cosmetics, or alcoholic beverages in a retail establishment which are packaged for sale to consumers.

hazard warning. Means any words, pictures, symbols, or combination thereof appearing on a label or other appropriate form of warning which convey the hazard(s) of the chemical(s) in the container(s).

health hazard. Chemicals which are carcinogens, toxic or highly toxic agents, reproductive toxins, irritants, corrosives, sensitizers, hepatotoxins, nephrotoxins, neurotoxins, agents which act on the hematopoietic system, and agents which damage the lungs, skin, eyes, or mucous membranes.

immediately dangerous to life or health (IDLH). Any atmospheric condition that poses an immediate threat to life, or which is likely to result in acute or immediate severe health effects. This includes oxygen deficiency conditions.

immediate use. Means that the hazardous chemical will be under the control of and used only by the person who transfers it from labeled container and only within the work shift in which it is transferred.

label. Any written, printed, or graphic material displayed on or affixed to containers of hazardous chemicals.

lower explosive limit (LEL). The minimum concentration of vapor in air below which propagation of a flame will not occur in the presence of an ignition source.

Material Safety Data Sheet (MSDS). See Appendix A.

odor threshold. A property displayed by a particular compound, low detection indicates a physiological sensation due to molecular contact with the olfactory nervous system (Based on 50 percent of the population).

Permissible Exposure Limit (PEL). Legally enforceable inhalation exposure limit usually expressed as a time-weighted average concentrations similar to (and in many cases derived from) the Threshold Limit Values.

physical hazard. A chemical which is either combustible, compressed gas, explosive, flammable, organic peroxide, oxidizer, pyrophoric, unstable (reactive) or water reactive.

produce. Manufacture, process, formulate, or repackage.

Recommended Exposure Limit (REL). An inhalation exposure limit defined by NIOSH similar to the Threshold Limit Values.

Threshold Limit Value - Time Weighted Average (TLV-TWA). The time-weighted average concentration for a normal 8-hour work day and a 40-hour work week, to which nearly all workers may be repeatedly exposed without adverse effect.

upper explosive limit (LEL). The maximum concentration of vapor in air above which propagation of a flame will not occur in the presence of an ignition source.

use. Package, handle, react, or transfer.

vapor pressure (V.P.). The pressure characteristic at any given temperature of a vapor in equilibrium with its liquid or solid form, often expressed in millimeters of mercury (mm Hg).

work area. A room or defined space in a workplace where hazardous chemicals are produced or used, and where employees are present.

workplace. An establishment, job site, or project, at one geographical location containing one or more work areas.

APPENDIX B-4

MSDSs

Genium Publishing Corporation
1145 Catalyn Street
Schenectady, NY 12303-1836 USA
(518) 377-8854

Material Safety Data Sheets Collection:

Sheet No. 316
Benzene

Issued: 11/78 Revision: E, 8/90

Section 1. Material Identification 32

Benzene (C_6H_6) Description: Derived by fractional distillation of coal tar, hydrodealkylation of toluene or pyrolysis of gasoline, catalytic reforming of petroleum, and transalkylation of toluene by disproportionation reaction. Used as a fuel; a chemical reagent; a solvent for a large number of materials such as paints, plastics, rubber, inks, oils, and fats; in manufacturing phenol, ethylbenzene (for styrene monomer), nitrobenzene (for aniline), dodecylbenzene (for detergents), cyclohexane (for nylon), chlorobenzene, diphenyl, benzene hexachloride, maleic anhydride, benzene-sulfonic acid, artificial leather, linoleum, oil cloth, varnishes, and lacquers; for printing and lithography; in dry cleaning; in adhesives and coatings; for extraction and rectification; as a degreasing agent; in the tire industry; and in shoe factories. Benzene has been banned as an ingredient in products intended for household use and is no longer used in pesticides.
Other Designations: CAS No. 0071-43-2, benzol, carbon oil, coal naphtha, cyclohexatriene, mineral naphtha, nitration benzene, phene, phenyl hydride, pyrobenzol.
Manufacturer: Contact your supplier or distributor. Consult the latest *Chemicalweek Buyers' Guide*[73] for a suppliers list.

R 1
I 4
S 2*
K 4
*Skin absorption

NFPA

HMIS
H 3
F 3
R 0
PPG†
† Sec. 8

Cautions: Benzene is a confirmed *human carcinogen* by the IARC. *Chronic low-level exposure may cause cancer (leukemia) and bone marrow damage, with injury to blood-forming tissue.* It is also a dangerous fire hazard when exposed to heat or flame.

Section 2. Ingredients and Occupational Exposure Limits

Benzene, ca 100%*

1989 OSHA PELs
(29 CFR 1910.1000, Table Z-1-A)
8-hr TWA: 1 ppm, 3 mg/m³
15-min STEL: 5 ppm, 15 mg/m³

(29 CFR 1910.1000, Table Z-2)
8-hr TWA: 10 ppm
Acceptable Ceiling Concentration: 25 ppm
Acceptable Maximum Peak: 50 ppm (10 min)†

1989-90 ACGIH
TLV-TWA: 10 ppm, 32 mg/m³

1988 NIOSH RELs
TWA: 0.1 ppm, 0.3 mg/m³
Ceiling: 1 ppm, 3 mg/m³

1985-86 Toxicity Data‡
Man, oral, LD_{Lo}: 50 mg/kg; no toxic effect noted
Man, inhalation, TC_{Lo}: 150 ppm inhaled intermittently over 1 yr in a number of discrete, separate doses affects the blood (other changes) and nutritional and gross metabolism (body temperature increase)
Rabbit, eye: 2 mg administered over 24 hr produces severe irritation

* OSHA 29 CFR 1910.1000, Subpart Z, states that the final benzene standard in 29 CFR 1910.1028 applies to all occupational exposures to benzene except in some subsegments of industry where exposures are consistently under the action level (i.e., distribution and sale of fuels, sealed containers and pipelines, coke production, oil and gas drilling and production, natural gas processing, and the percentage exclusion for liquid mixtures); for the excepted subsegments, the benzene limits in Table Z-2 apply.
† Acceptable maximum peak above the acceptable ceiling concentration for an 8-hr shift.
‡ See NIOSH, *RTECS* (CY1400000), for additional irritative, mutative, reproductive, tumorigenic, and toxicity data.

Section 3. Physical Data

Boiling Point: 176 °F (80 °C)
Melting Point: 42 °F (5.5 °C)
Vapor Pressure: 100 mm Hg at 79 °F (26.1 °C)
Vapor Density (Air = 1): 2.7
Evaporation Rate (Ether = 1): 2.8
Molecular Weight: 78.11
Specific Gravity (15 °C/4 °C): 0.8787
Water Solubility: Slightly (0.180 g/100 g of H_2O at 25 °C)
% Volatile by Volume: 100
Viscosity: 0.6468 mPa at 20 °C

Appearance and Odor: A colorless liquid with a characteristic sweet, aromatic odor. The odor recognition threshold (100% of panel) is approximately 5 ppm (unfatigued) in air. Odor *is not* an adequate warning of hazard.

Section 4. Fire and Explosion Data

Flash Point: 12 °F (-11.1 °C), CC	Autoignition Temperature: 928 °F (498 °C)	LEL: 1.3% v/v	UEL: 7.1% v/v

Extinguishing Media: Use dry chemical, foam, or carbon dioxide to extinguish benzene fires. Water may be ineffective as an extinguishing agent since it can scatter and spread the fire. Use water spray to cool fire-exposed containers, flush spills away from exposures, disperse benzene vapor, and protect personnel attempting to stop an unignited benzene leak.
Unusual Fire or Explosion Hazards: Benzene is a Class 1B flammable liquid. A concentration exceeding 3250 ppm is considered a potential fire explosion hazard. Benzene vapor is heavier than air and can collect in low lying areas or travel to an ignition source and flash back. Explosive and flammable benzene vapor-air mixtures can easily form at room temperature. Eliminate all ignition sources where benzene is used, handled, or stored.
Special Fire-fighting Procedures: Isolate hazard area and deny entry. Since fire may produce toxic fumes, wear a self-contained breathing apparatus (SCBA) with a full facepiece operated in the pressure-demand or positive-pressure mode and full protective equipment. Structural firefighter's protective clothing provides limited protection. Stay out of low areas. Be aware of runoff from fire control methods. Do not release to sewers or waterways. Runoff to sewer can create pollution, fire, and explosion hazard.

Section 5. Reactivity Data

Stability/Polymerization: Benzene is stable at room temperature in closed containers under normal storage and handling conditions. Hazardous polymerization cannot occur.
Chemical Incompatibilities: Benzene explodes on contact with diborane, permanganic acid, bromine pentafluoride, peroxodisulfuric acid, and peroxomonosulfuric acid. It ignites on contact with dioxygen difluoride, dioxygenyl tetrafluoroborate, iodine heptafluoride, and sodium peroxide + water. Benzene forms sensitive, explosive mixture with iodine pentafluoride, ozone, liquid oxygen, silver perchlorate, nitryl perchlorate, nitric acid, and arsenic pentafluoride + potassium methoxide (explodes above 30 °C). A vigorous or incandescent reaction occurs with bromine trifluoride, uranium hexafluoride, and hydrogen + Raney nickel [above 410 °F (210 °C)]. Benzene is incompatible with oxidizing materials.
Conditions to Avoid: Avoid heat and ignition sources.
Hazardous Products of Decomposition: Thermal oxidative decomposition of benzene can produce toxic gases and vapors such as carbon monoxide.

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Section 6. Health Hazard Data

Carcinogenicity: The ACGIH, OSHA, and IARC list benzene as, respectively, a supected human carcinogen, a cancer hazard, and, based on sufficient human and animal evidence, a human carcinogen (Group 1).
Summary of Risks: Prolonged skin contact or excessive inhalation of benzene vapor may cause headache, weakness, appetite loss, and fatigue. The most important health hazards are cancer (leukemia) and bone marrow damage with injury to blood-forming tissue from chronic low-level exposure. Higher level exposures may irritate the respiratory tract and cause central nervous system (CNS) depression.
Medical Conditions Aggravated by Long-Term Exposure: Exposure may worsen ailments of the heart, lungs, liver, kidneys, blood, and CNS.
Target Organs: Blood, central nervous system, bone marrow, eyes, upper respiratory tract, and skin.
Primary Entry Routes: Inhalation, skin contact.
Acute Effects: Symptoms of acute overexposure include irritation of the eyes, nose, and respiratory tract, breathlessness, euphoria, nausea, drowsiness, headache, dizziness, and intoxication. Severe exposure may lead to convulsions and unconsciousness. Skin contact may cause a drying rash (dermatitis).
Chronic Effects: Long-term chronic exposure may result in many blood disorders ranging from aplastic anemia (an inability to form blood cells) to leukemia.
FIRST AID
Eyes: Gently lift the eyelids and flush immediately and continuously with flooding amounts of water until transported to an emergency medical facility. Consult a physician immediately.
Skin: *Quickly* remove contaminated clothing. Immediately rinse with flooding amounts of water for at least 15 min. For reddened or blistered skin, consult a physician. Wash affected area with soap and water.
Inhalation: Remove exposed person to fresh air. Emergency personnel should protect against inhalation exposure. Provide CPR to support breathing or circulation as necessary. Keep awake and transport to a medical facility.
Ingestion: Never give anything by mouth to an unconscious or convulsing person. If ingested, *do not induce vomiting* since aspiration may be fatal. Call a physician immediately.
After first aid, get appropriate in-plant, paramedic, or community medical support.
Physician's Note: Evaluate chronic exposure with a CBC, peripheral smear, and reticulocyte count for signs of myelotoxicity. Follow up any early indicators of leukemia with a bone marrow biopsy. Urinary phenol conjugates may be used for biological monitoring of recent exposure. Acute management is primarily supportive for CNS depression.

Section 7. Spill, Leak, and Disposal Procedures

Spill/Leak: *Design and practice a benzene spill control and countermeasure plan (SCCP).* Notify safety personnel, evacuate all unnecessary personnel, eliminate all heat and ignition sources, and provide adequate ventilation. Cleanup personnel should protect against vapor inhalation, eye contact, and skin absorption. Absorb as much benzene as possible with an inert, noncombustible material. For large spills, dike far ahead of spill and contain liquid. Use nonsparking tools to place waste liquid or absorbent into closable containers for disposal. Keep waste out of confined spaces such as sewers, watersheds, and waterways because of explosion danger. Follow applicable OSHA regulations (29 CFR 1910.120).
Disposal: Contact your supplier or a licensed contractor for detailed recommendations. Follow applicable Federal, state, and local regulations.
EPA Designations
Listed as a RCRA Hazardous Waste (40 CFR 261.33), Hazardous Waste No. U019
Listed as a CERCLA Hazardous Substance* (40 CFR 302.4), Reportable Quantity (RQ): 1000 lb (454 kg) [* per Clean Water Act, Sec. 307 (a), 311 (b)(4), 112; and per RCRA, Sec. 3001]
SARA Extremely Hazardous Substance (40 CFR 355): Not listed
Listed as SARA Toxic Chemical (40 CFR 372.65)
OSHA Designations
Listed as an Air Contaminant (29 CFR 1910.1000, Tables Z-1-A and Z-2)

Section 8. Special Protection Data

Goggles: Wear protective eyeglasses or chemical safety goggles, per OSHA eye- and face-protection regulations (29 CFR 1910.133).
Respirator: Seek professional advice prior to respirator selection and use. Follow OSHA respirator regulations (29 CFR 1910.134) and, if necessary, wear a NIOSH-approved respirator. For emergency or nonroutine operations (cleaning spills, reactor vessels, or storage tanks), wear an SCBA. *Warning! Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.*
Other: Wear impervious gloves, boots, aprons, and gauntlets to prevent skin contact.
Ventilation: Provide general and local explosion-proof ventilation systems to maintain airborne concentrations at least below the OSHA PELs (Sec. 2). Local exhaust ventilation is preferred since it prevents contaminant dispersion into the work area by controlling it at its source.[103]
Safety Stations: Make available in the work area emergency eyewash stations, safety/quick-drench showers, and washing facilities.
Contaminated Equipment: Never wear contact lenses in the work area: soft lenses may absorb, and all lenses concentrate, irritants. Remove this material from your shoes and equipment. Launder contaminated clothing before wearing.
Comments: Never eat, drink, or smoke in work areas. Practice good personal hygiene after using this material, especially before eating, drinking, smoking, using the toilet, or applying cosmetics.

Section 9. Special Precautions and Comments

Storage Requirements: Store in tightly closed containers in a cool, dry, well-ventilated area away from all heat and ignition sources and incompatible materials. *Caution! Benzene vapor may form explosive mixtures in air.* To prevent static sparks, electrically ground and bond all containers and equipment used in shipping, receiving, or transferring operations in production and storage areas. When opening or closing benzene containers, use nonsparking tools. Keep fire extinguishers readily available.
Engineering Controls: Because OSHA specifically regulates benzene (29 CFR 1910.1028), educate workers about its potential hazards and dangers. Minimize all possible exposures to carcinogens. If possible, substitute less toxic solvents for benzene; use this material with extreme caution and only if absolutely essential. Avoid vapor inhalation and skin and eye contact. Use only with adequate ventilation and appropriate personal protective gear. Institute a respiratory protection program that includes regular training, maintenance, inspection, and evaluation. Designate regulated areas of benzene use (see legend in the box below) and label benzene containers with "DANGER, CONTAINS BENZENE, CANCER HAZARD."
Other Precautions: Provide preplacement and periodic medical examinations with emphasis on a history of blood disease or previous exposure.

Transportation Data (49 CFR 172.101, .102)

DOT Shipping Name: Benzene (*benzol*)	**IMO Shipping Name:** Benzene
DOT Hazard Class: Flammable liquid	**IMO Hazard Class:** 3.2
ID No.: UN1114	**ID No.:** UN1114
DOT Label: Flammable liquid	**IMO Label:** Flammable liquid
DOT Packaging Exceptions: 173.118	**IMDG Packaging Group:** II
DOT Packaging Requirements: 173.119	

DANGER
BENZENE
CANCER HAZARD
FLAMMABLE–NO SMOKING
AUTHORIZED PERSONNEL ONLY
RESPIRATOR REQUIRED

MSDS Collection References: 1, 2, 12, 26, 73, 84-94, 100, 101, 103, 109, 124, 126, 127, 132, 134, 136, 138, 139, 143
Prepared by: MJ Allison, BS; Industrial Hygiene Review: DJ Wilson, CIH; Medical Review: MJ Upfal, MD, MPH; Edited by: JR Stuart, MS

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Material Safety Data Sheets Collection:
Sheet No. 317
Toluene
Issued: 8/79 Revision: E, 9/92 Errata: 2/94

Section 1. Material Identification

Toluene ($C_6H_5CH_3$) Description: Derived from petroleum i.e., dehydrogenation of cycloparaffin fractions followed by the aromatization of saturated aromatic hydrocarbons or by fractional distillation of coal-tar light oil and purified by rectification. Used widely as a solvent (replacing benzene in many cases) for oils, resins, adhesives, natural rubber, coal tar, asphalt, pitch, acetyl celluloses, cellulose paints and varnishes; a diluent for photogravure inks, raw material for organic synthesis (benzoyl & benzilidene chlorides, saccharine, TNT, toluene diisocyanate, and many dyestuffs), in aviation and high octane automobile gasoline, as a nonclinical thermometer liquid and suspension solution for navigational instruments.
Other Designations: CAS No. 108-88-3, Methacide, methylbenzene, methylbenzol, phenylmethane, toluol, Tolu-sol.
Manufacturer: Contact your supplier or distributor. Consult latest *Chemical Week Buyers' Guide*[73] for a suppliers list.

Cautions: Toluene is an eye, skin, and respiratory tract irritant becoming narcotic at high centrations. Liver and kidney damage has occurred. Pregnant women chronically exposed to toluene have shown teratogenic effects. Toluene is highly flammable.

NFPA
R 1
I 3
S 2*
K 3
* Skin absorption

HMIS
H 2- Chronic effects
F 3
R 0
PPE-Sec. 8

Section 2. Ingredients and Occupational Exposure Limits

Toluene, < 100%; may contain a small amount of benzene (~ 1%), xylene, and nonaromatic hydrocarbons.

1991 OSHA PELs
8-hr TWA: 100 ppm (375 mg/m^3)
15-min STEL: 150 ppm (560 mg/m^3)

1990 IDLH Level
2000 ppm

1990 NIOSH RELs
TWA: 100 ppm (375 mg/m^3)
STEL: 150 ppm (560 mg/m^3)

1992-93 ACGIH TLV (Skin)
TWA: 50 ppm (188 mg/m^3)

1990 DFG (Germany) MAK*
TWA: 100 ppm (380 mg/m^3)
Half-life: 2 hr to end of shift
Category II: Substances with systemic effects
Peak Exposure Limit: 500 ppm, 30 min average value, 2/shift

1985-86 Toxicity Data†
Man, inhalation, TC_{Lo}: 100 ppm caused hallucinations, and changes in motor activity and changes in psychophysiological tests.
Human, oral, LD_{Lo}: 50 mg/kg; toxic effects not yet reviewed
Human, eye: 300 ppm caused irritation.
Rat, oral, LD_{50}: 5000 mg/kg
Rat, liver: 30 µmol/L caused DNA damage.

* Available information suggests damage to the developing fetus is probable.
†See NIOSH, *RTECS* (XS5250000), for additional irritation, mutation, reproductive, and toxicity data.

Section 3. Physical Data

Boiling Point: 232 °F (110.6 °C)
Melting Point: -139 °F (-95 °C)
Molecular Weight: 92.15
Density: 0.866 at 68 °F (20/4 °C)
Surface Tension: 29 dyne/cm at 68 °F (20 °C)
Viscosity: 0.59 cP at 68 °F (20 °C)
Refraction Index: 1.4967 at 20 °C/D

Water Solubility: Very slightly soluble, 0.6 mg/L at 68 °F (20 °C)
Other Solubilities: Soluble in acetone, alcohol, ether, benzene, chloroform, glacial acetic acid, petroleum ether, and carbon disulfide.
Vapor Pressure: 22 mm Hg at 68 °F (20 °C); 36.7 mm Hg at 86 °F (30 °C)
Saturated Vapor Density (Air = 0.075 lb/ft^3 or 1.2 kg/m^3): 0.0797 lb/ft^3 or 1.2755 kg/m^3
Odor Threshold (range of all referenced values): 0.021 to 69 ppm

Appearance and Odor: Colorless liquid with a sickly sweet odor.

Section 4. Fire and Explosion Data

Flash Point: 40 °F (4.4 °C) CC	Autoignition Temperature: 896 °F (480 °C)	LEL: 1.27% v/v	UEL: 7.0% v/v

Extinguishing Media: Toluene is a Class 1B flammable liquid. To fight fire, use dry chemical carbon dioxide, or 'alcohol-resistant' foam. Water spray may be ineffective as toluene floats on water and may actually spread fire. **Unusual Fire or Explosion Hazards:** Concentrated vapors are heavier than air and may travel to an ignition source and flash back. Container may explode in heat of fire. Toluenes' burning rate = 5.7 mm/min and its flame speed = 37 cm/sec. Vapor poses an explosion hazard indoors, outdoors, and in sewers. May accumulate static electricity. **Special Fire-fighting Procedures:** Because fire may produce toxic thermal decomposition products, wear a self-contained breathing apparatus (SCBA) with a full facepiece operated in pressure-demand or positive-pressure mode. Structural firefighter's protective clothing provides only limited protection. Apply cooling water to sides of tanks until well after fire is out. Stay away from ends of tanks. For massive fire in cargo area, use monitor nozzles or unmanned hose holders; if impossible, withdraw from fire and let burn. Withdraw immediately if you hear a rising sound from venting safety device or notice any tank discoloration due to fire because a BLEVE (boiling liquid expanding vapor explosion) may be imminent. Do not release runoff from fire control methods to sewers or waterways.

Section 5. Reactivity Data

Stability/Polymerization: Toluene is stable at room temperature in closed containers under normal storage and handling conditions. Hazardous polymerization can't occur. **Chemical Incompatibilities:** Strong oxidizers, concentrated nitric acid, nitric acid + sulfuric acid, dinitrogen tetroxide, silver perchlorate, bromine trifluoride, tetranitromethane, and 1,3-dichloro-5,5-dimethyl-2,4-imidazolididione. **Conditions to Avoid:** Contact with heat, ignition sources, or incompatibles. **Hazardous Products of Decomposition:** Thermal oxidative decomposition of toluene can produce carbon dioxide, and acrid, irritating smoke.

Section 6. Health Hazard Data

Carcinogenicity: The IARC,[164] NTP,[169] and OSHA[164] do not list toluene as a carcinogen. **Summary of Risks:** Toluene is irritating to the eyes, nose, and respiratory tract. Inhalation of high concentrations produces a narcotic effect sometimes leading to coma as well as liver and kidney damage. 93% of inhaled toluene is retained in the body of which 80% is metabolized to benzoic acid, then to hippuric acid and excreted in urine. The remainder is metabolized to *o*-cresol and excreted or exhaled unchanged. Toluene metabolism is inhibited by alcohol ingestion and is synergistic with benzene, asphalt fumes, or chlorinated hydrocarbons (i.e. perchloroethylene). Toluene is readily absorbed through the skin at 14 to 23 mg/cm^2/hr. Toluene is absorbed quicker during exercise than at rest and appears to be retained longer in obese versus thin victims; presumably due to its lipid solubility. There is inconsistent data on toluene's ability to damage bone marrow; chronic poisoning has resulted in anemia and leucopenia with biopsy showing bone marrow hypo-plasia. These reports are few and some authorities argue that the effects may have been due to benzene contaminants. Chronic inhalation during pregnancy has been associated with teratogenic effects on the fetus including microcephaly, CNS dysfunction, attentional deficits, developmental delay + language impairment, growth retardation, and physical defects including a small midface, short palpebral fissures, with deep-set eyes, low-set ears, flat nasal bridge with a small nose, micrognathia, and blunt fingertips. There is some evidence that toluene causes an autoimmune illness in which the body produces antibodies that cause inflammation of its own kidney.

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Section 6. Health Hazard Data

Medical Conditions Aggravated by Long-Term Exposure: Alcoholism and CNS, kidney, skin, or liver disease. **Target Organs:** CNS, liver, kidney, skin. **Primary Entry Routes:** Inhalation, skin contact/absorption. **Acute Effects:** Vapor inhalation causes respiratory tract irritation, fatigue, weakness, confusion, dizziness, headache, dilated pupils, watering eyes, nervousness, insomnia, parasthesis, and vertigo progressing to narcotic coma. Death may result from cardiac arrest due to ventricular fibrillation with catecholamines loss. Liquid splashed in the eye causes conjunctival irritation, irritation corneal damage and possible burns. Prolonged skin contact leads to drying and fissured dermatitis. Ingestion causes GI tract irritation and symptoms associated with inhalation. **Chronic Effects:** Symptoms include mucous membrane irritation, headache, vertigo, nausea, appetite loss and alcohol intolerance. Repeated heavy exposure may result in encephalopathies (cerebellar ataxia and cognitive dysfunction), liver enlargement, and kidney dystrophy (wasting away). Symptoms usually appear at workdays end, worsen at weeks end and decrease or disappear over the weekend. **FIRST AID** **Eyes:** *Do not* allow victim to rub or keep eyes tightly shut. Gently lift eyelids and flush immediately and continuously with flooding amounts of water until transported to an emergency medical facility. Consult an ophthalmologist immediately. **Skin:** *Quickly* remove contaminated clothing. Rinse with flooding amounts of water for at least 15 min. Wash exposed area with soap and water. **Inhalation:** Remove exposed person to fresh air and support breathing as needed. **Ingestion:** Never give anything by mouth to an unconscious or convulsing person. Contact a poison control center and unless otherwise advised, have that *conscious and alert* person drink 1 to 2 glasses of water to dilute. *Do not* induce vomiting because of danger of aspiration into the lungs. Gastric lavage may be indicated if large amounts are swallowed; potential toxicity needs to be weighed against aspiration risk when deciding for or against gastric lavage. **Note to Physicians:** Monitor cardiac function. If indicated, use epinephrine and other catecholamines carefully, because of the possibility of a lowered myocardial threshold to the arrhythmogenic effects of such substances. Obtain CBC, electrolytes, and urinalysis. Monitor arterial blood gases. If toluene has > 0.02% (200 ppm) benzene, evaluate for potential benzene toxicity. BEI: hippuric acid in urine, sample at shift end (2.5 g/g creatinine); Toluene in venous blood, sample at shift end (1.0 mg/L).

Section 7. Spill, Leak, and Disposal Procedures

Spill/Leak: Notify safety personnel, isolate and ventilate area, deny entry, and stay upwind. Cleanup personnel protect against inhalation and skin/eye contact. Use water spray to cool and disperse vapors but it may not prevent ignition in closed spaces. Cellosolve, hycar absorbent materials, and fluorocarbon water can also be used for vapor suppression/containment. Take up small spill with earth, sand, vermiculite, or other absorbent, noncombustible material. Dike far ahead of large spills for later reclamation or disposal. For water spills, (10 ppm or greater) apply activated carbon at 10X the spilled amount and remove trapped material with suction hoses or use mechanical dredges/lifts to remove immobilized masses of pollutants and precipitates. Toluene can undergo fluidized bed incineration at 842 to 1796 °F (450 to 980 °C), rotary kiln incineration at 1508 to 2912 °F (820 to 1600 °C), or liquid injection incineration at 1202 to 2912 °F (650 to 1600 °C). Follow applicable OSHA regulations (29 CFR 1910.120). **Ecotoxicity Values:** Blue gill, LC_{50} = 17 mg/L/24 hr; shrimp (*Crangonfracis coron*), LC_{50} = 4.3 ppm/96 hr; fathead minnow (*Pimephales promelas*), LC_{50} = 36.2 mg/L/96 hr. **Environmental Degradation:** If released to land, toluene evaporates and undergoes microbial degradation. In water, toluene volatilizes and biodegrades with a half-life of days to several weeks. In air, toluene degrades by reaction with photochemically produced hydroxyl radicals. **Disposal:** Treat contaminated water by gravity separation of solids, followed by skimming of surface. Pass through dual media filtration and carbon absorption units (carbon ratio 1 kg to 10 kg soluble material). Return waste water from backwash to gravity separator. Contact your supplier or a licensed contractor for detailed recommendations. Follow applicable Federal, state, and local regulations.

EPA Designations
Listed as a RCRA Hazardous Waste (40 CFR 261.33): No. U220
SARA Extremely Hazardous Substance (40 CFR 355), TPQ: Not listed
Listed as a CERCLA Hazardous Substance* (40 CFR 302.4): Final Reportable Quantity (RQ), 1000 lb (454 kg)
[RCRA, Sec. 3001; CWA, Sec. 311 (b)(4); CWA, Sec. 307 (a)]
Listed as a SARA Toxic Chemical (40 CFR 372.65): Not listed

OSHA Designations
Listed as an Air Contaminant (29 CFR 1910.1000, Table Z-1-A)

Section 8. Special Protection Data

Goggles: Wear protective eyeglasses with shatter-resistant glass and side-shields or chemical safety goggles, per OSHA eye- and face-protection regulations (29 CFR 1910.133). Because contact lens use in industry is controversial, establish your own policy. **Respirator:** Seek professional advice prior to respirator selection and use. Follow OSHA respirator regulations (29 CFR 1910.134) and, if necessary, wear a MSHA/NIOSH-approved respirator. For < 1000 ppm, use any chemical cartridge respirator with appropriate organic vapor cartridges, any supplied-air respirator (SAR), or SCBA. For < 2000 ppm, use any SAR operated in continuous-flow mode, any SAR or SCBA with a full facepiece, or any air-purifying respirator with a full facepiece having a chin-style, front or back mounted organic vapor canister. For emergency or nonroutine operations (cleaning spills, reactor vessels, or storage tanks), wear an SCBA. *Warning! Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.* If respirators are used, OSHA requires a written respiratory protection program that includes at least: medical certification, training, fit-testing, periodic environmental monitoring, maintenance, inspection, cleaning, and convenient, sanitary storage areas. **Other:** Wear chemically protective gloves, boots, aprons, and gauntlets to prevent skin contact. Polyvinyl alcohol with a breakthrough time of > 8 hr, Teflon and Viton are recommended as suitable materials for PPE. **Ventilation:** Provide general and local exhaust ventilation systems to maintain airborne concentrations below the OSHA PELs (Sec. 2). Local exhaust ventilation is preferred because it prevents contaminant dispersion into the work area by controlling it at its source.[103] **Safety Stations:** Make available in the work area emergency eyewash stations, safety/quick-drench showers, and washing facilities. **Contaminated Equipment:** Separate contaminated work clothes from street clothes and launder before reuse. Remove toluene from your shoes and clean PPE. **Comments:** Never eat, drink, or smoke in work areas. Practice good personal hygiene after using this material, especially before eating, drinking, smoking, using the toilet, or applying cosmetics.

Section 9. Special Precautions and Comments

Storage Requirements: Prevent physical damage to containers. Store in a cool, dry, well-ventilated area away from ignition sources and incompatibles. Outside or detached storage is preferred. If stored inside, use a standard flammable liquids warehouse, room, or cabinet. To prevent static sparks, electrically ground and bond all equipment used with toluene. Do not use open lights in toluene areas. Install Class 1, Group D electrical equipment. Check that toluene is free of or contains < 1% benzene before use. **Engineering Controls:** To reduce potential health hazards, use sufficient dilution or local exhaust ventilation to control airborne contaminants and to maintain concentrations at the lowest practical level. **Administrative Controls:** Adopt controls for confined spaces (29 CFR 1910.146) if entering areas of unknown toluene levels (holes, wells, storage tanks). Consider preplacement and periodic medical exams of exposed workers that emphasize the CNS, liver, kidney, and skin. Include hemocytometric and thrombocyte count in cases where benzene is a contaminant of toluene. Monitor air at regular intervals to ensure effective ventilation.

Transportation Data (49 CFR 172.101)

DOT Shipping Name: Toluene
DOT Hazard Class: 3
I.D. #: UN1294
DOT Packing Group: II
DOT Label: Flammable Liquid
Special Provisions (172.102): T1

Packaging Authorizations
a) Exceptions: 150
b) Non-bulk Packaging: 202
c) Bulk Packaging: 242

Quantity Limitations
a) Passenger Aircraft or Railcar: 5L
b) Cargo Aircraft Only: 60L

Vessel Stowage Requirements
Vessel Stowage: B
Other: --

MSDS Collection References: 26, 73, 100, 101, 103, 124, 126, 127, 132, 140, 148, 153, 159, 163, 164, 167, 169, 171, 174, 175, 176, 180.
Prepared by: M Gannon, BA; Industrial Hygiene Review: PA Roy, CIH, MPH; Medical Review: AC Darlington, MD, MPH

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Material Safety Data Sheets Collection:

Sheet No. 385
Ethylbenzene

Issued: 8/78 Revision: B, 9/92

Section 1. Material Identification

Ethylbenzene ($C_6H_5C_2H_5$) Description: Derived by heating benzene and ethylene in presence of aluminum chloride with subsequent distillation, by fractionation directly from the mixed xylene stream in petroleum refining, or dehydrogenation of naphthenes. Used as a solvent, an antiknock agent in gasoline; and as an intermediate in production of synthetic rubber, styrene, cellulose acetate, diethylbenzene, acetophenone, ethyl anthraquinone, propyl oxide, and α-methylbenzol alcohol.
Other Designations: CAS No. 100-41-4, ethylbenzol, EB, phenylethane, NCI-C56393.
Manufacturer: Contact your supplier or distributor. Consult latest *Chemical Week Buyers' Guide*[73] for a suppliers list.

R 1
I 3
S 2*
K 4
* Skin absorption

NFPA
3 / 2 / 0 / -

HMIS
H 2†
F 3
R 0
PPE - Sec. 8
† Chronic effects

Cautions: Ethylbenzene is a skin and mucous membrane irritant considered the most irritating of the benzene series. Inhalation causes acute and chronic central nervous system (CNS) effects. It is highly flammable and forms explosive mixtures with air.

Section 2. Ingredients and Occupational Exposure Limits

Ethylbenzene, ca >99.0%. Impurities include ~ 0.1% *meta & para* xylene, ~ 0.1% cumene, and ~ 0.1% toluene.

1991 OSHA PELs
8-hr TWA: 100 ppm (435 mg/m^3)
15-min STEL: 125 ppm (545 mg/m^3)
Action Level: 50 ppm (217 mg/m^3)

1990 IDLH Level
2000 ppm

1990 NIOSH REL
TWA: 100 ppm (435 mg/m^3)
STEL: 125 ppm (545 mg/m^3)

1992-93 ACGIH TLVs
TWA: 100 ppm (434 mg/m^3)
STEL: 125 ppm (545 mg/m^3)

1990 DFG (Germany) MAK
TWA: 100 ppm (440 mg/m^3)
Category 1: local irritants
Peak Exposure Limit: 200 ppm, 5 min momentary value, max of 8/shift
Danger of cutaneous absorption

1985-86 Toxicity Data*
Human, inhalation, TC_{Lo}: 100 ppm/8 hr caused eye effects, sleep, and respiratory changes.
Human, lymphocyte: 1 mmol/L induced sister chromatid exchange.
Rat, oral, LD_{50}: 3500 mg/kg; toxic effects not yet reviewed
Rat (female), inhalation, TC_{Lo}: 1000 ppm/7 hr/day, 5 days/wk, for 3 wk prior to mating and daily for 19 days of gestation produced pups with high incidence of extra ribs.[179]

* See NIOSH, *RTECS* (DA0700000), for additional irritation, mutation, reproductive, and toxicity data.

Section 3. Physical Data

Boiling Point: 277 °F (136 °C)
Melting Point: -139 °F (-95 °C)
Surface Tension: 31.5 dyne/cm
Ionization Potential: 8.76 eV
Viscosity: 0.64 cP at 77 °F (25 °C)
Refraction Index: 1.4959 at 68 °F (20 °C)
Relative Evaporation Rate (ether = 1): 0.0106
Bulk Density: 7.21 lb/Gal at 77 °F (25 °C)
Critical Temperature: 651 °F (343.9 °C)
Critical Pressure: 35.6 atm

Molecular Weight: 106.16
Density: 0.863 at 77 °F (25 °C)
Water Solubility: Slightly, 14 mg/100 mL at 59 °F (15 °C)
Other Solubilities: Miscible in alcohol, ether; soluble in carbon tetrachloride, benzene, sulfur dioxide, and many organic solvents; insoluble in ammonia
Odor Threshold: 2.3 ppm
Vapor Pressure: 7.1 mm Hg at 68 °F (20 °C); 10 mmHg at 78.62 °F (25.9 °C); 100 mm Hg 165.38 °F (74.1 °C)
Saturated Vapor Density (Air = 0.075 lb/ft^3 or 1.2 kg/m^3): 0.0768 lb/ft^3 or 1.2298 kg/m^3

Appearance and Odor: Colorless, flammable liquid with a pungent odor.

Section 4. Fire and Explosion Data

Flash Point: 64 °F (18 °C) CC	Autoignition Temperature: 810 °F (432 °C)	LEL: 1.0% v/v	UEL: 6.7% v/v

Extinguishing Media: Class 1B Flammable liquid. For small fires, use dry chemical, carbon dioxide, or 'alcohol-resistant' foam. For large fires, use fog or 'alcohol-resistant' foam. Use water only if other agents are unavailable; EB floats on water and may travel to an ignition source and spread fire. **Unusual Fire or Explosion Hazards:** Burning rate = 5.8 mm/min. Vapors may travel to an ignition source and flash back. Container may explode in heat of fire. EB poses a vapor explosion hazard indoors, outdoors, and in sewers. **Special Fire-fighting Procedures:** Because fire may produce toxic thermal decomposition products, wear a self-contained breathing apparatus (SCBA) with a full facepiece operated in pressure-demand or positive-pressure mode. Cool container sides with water until well after fire is out. Stay away from ends of tanks. For massive fire in cargo area, use monitor nozzles or unmanned hose holders; if impossible, withdraw from area and let fire burn. Withdraw immediately if you hear rising sound from venting safety device or notice any tank discoloration due to fire. Do not release runoff from fire control methods to sewers or waterways.

Section 5. Reactivity Data

Stability/Polymerization: Ethylbenzene is stable at room temperature in closed containers under normal storage and handling conditions. Hazardous polymerization cannot occur.
Chemical Incompatibilities: Reacts vigorously with oxidizers.
Conditions to Avoid: Exposure to heat and oxidizers.
Hazardous Products of Decomposition: Thermal oxidative decomposition of EB can produce acrid smoke and irritating fumes.

Section 6. Health Hazard Data

Carcinogenicity: The IARC,[164] NTP,[169] and OSHA[164] do not list EB as a carcinogen. **Summary of Risks:** Occupational exposure to EB alone is rare since it is usually present together with other solvents. EB is irritating to the eyes, skin, and respiratory tract. Vapor inhalation produces varying degrees of CNS effects depending on concentration. The liquid is absorbed through the skin but vapors are not. 56 to 64% of inhaled ethylbenzene is retained and metabolized. Urinary metabolites following exposure to 23 to 85 ppm for 8 hr are mandelic acid (64%), phenylglyoxylic acid (25%), and methylphenylcarbinol/1-phenyl ethanol (5%). Concurrent exposure to xylene and ethylbenzene causes slower excretion of EB metabolites. Based on the rat LD_{50}, one manufacturer gives 3 to 4 oz. as the lethal dose for a 100 lb person.

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Section 6. Health Hazard Data

Medical Conditions Aggravated by Long-Term Exposure: Skin and CNS diseases and impaired pulmonary function (especially obstructive rway disease). **Target Organs:** Eyes, respiratory system, skin, CNS, blood. **Primary Entry Routes:** Inhalation, skin and eye contact. **Acute Effects:** Vapor inhalation of 200 ppm caused transient eye irritation; 1000 ppm caused eye irritation with profuse watering (tolerance developed rapidly); 2000 ppm caused severe and immediate eye irritation and watering, nasal irritation, chest constriction, and vertigo; 5000 ppm was intolerable and caused eye and nose irritation. Inhalation of high concentrations may cause narcosis, cramps, and death due to respiratory paralysis. Skin exposed to pure ethylbenzene for 10 to 15 min absorbed 22 to 33 mg/cm^2/hr. Immersion of hand in solutions of 112 & 156 mg/L for 1 hr absorbed 118 & 215.7 µg/cm^2/hr, respectively. **Chronic Effects:** Repeated skin contact may cause dryness, scaling, and fissuring. Workers chronically exposed to > 100 ppm complained of fatigue, sleepiness, headache, and mild irritation of the eyes and respiratory tract. Repeated vapor inhalation may result in blood disorders, particularly leukopenia (abnormally low level of white blood cells) and lymphocytosis.

FIRST AID

Eyes: *Do not* allow victim to rub or keep eyes tightly shut. Gently lift eyelids and flush immediately and continuously with flooding amounts of water until transported to an emergency medical facility. Consult a physician immediately. **Skin:** *Quickly* remove contaminated clothing. Rinse with flooding amounts of water for at least 15 min. Wash exposed area with soap and water. For reddened or blistered skin, consult a physician. **Inhalation:** Remove exposed person to fresh air and support breathing as needed. **Ingestion:** Never give anything by mouth to an unconscious or convulsing person. Contact a poison control center and unless otherwise advised, have that *conscious and alert* person drink 1 to 2 glasses of water to dilute. *Do not* induce vomiting! Aspiration of even a small amount of EB in vomitus can cause severe damage since its low viscosity and surface tension will cause it to spread over a large area of the lung tissue.

After first aid, get appropriate in-plant, paramedic, or community medical support.

Note to Physicians: BEI = mandelic acid in urine (1.5 g/g of creatinine), sample at end of shift at workweeks end. Since this test is not specific, test for EB in expired air for confirmation.

Section 7. Spill, Leak, and Disposal Procedures

Spill/Leak: Notify safety personnel. Isolate and ventilate area, deny entry and stay upwind. Shut off all ignition sources. Cleanup personnel should protect against vapor inhalation and skin/eye contact. Take up small spills with earth, sand, vermiculite, or other absorbent, noncombustible material and place in suitable container. Dike far ahead of large spill for later reclamation or disposal. Report any release >1000 lb. Follow applicable OSHA regulations (29 CFR 1910.120). **Environmental Transport:** If released to soil, EB partially evaporates into the atmosphere, with a half-life of hrs to wks, and some leaches into groundwater, especially in soil with low organic carbon content. Biodegradation occurs with a half-life of 2 days. Some EB may absorb to sediment or bioconcentrate in fish. Evidence points to slow biodegradation in groundwater. In air, it reacts with photochemically produced hydroxyl radicals with a half-life of hrs to 2 days. Additional amounts may be removed by rain. **Ecotoxicity Values:** Shrimp (*Mysidopsis bahia*), LC_{50} = 87.6 mg/L/96 hr; sheepshead minnow (*Cyprinodon variegatus*) LC_{50} = 275 mg/L/96 hr; fathead minnow (*Pimephales promelas*) LC_{50} = 42.3 mg/L/96 hr in hard water & 48.5 mg/L/96 hr in softwater. **Disposal:** A candidate for rotary kiln incineration at 1508 to 2912°F (820 to 1600°C), liquid injection incineration at 1202 to 2912°F (650 to 1600°C), and fluidized bed incineration at 842 to 1796°F (450 to 980°C). Contact your supplier or a licensed contractor for detailed recommendations. Follow applicable Federal, state, and local regulations.

EPA Designations

isted as a RCRA Hazardous Waste (40 CFR 261.21): No. D001

Listed as a SARA Toxic Chemical (40 CFR 372.65)

SARA Extremely Hazardous Substance (40 CFR 355), TPQ: Not listed

Listed as a CERCLA Hazardous Substance* (40 CFR 302.4): Final Reportable Quantity (RQ), 1000 lb (454 kg) [* per CWA, Sec. 311 (b)(4) & CWA, Sec. 307 (a)]

OSHA Designations

Listed as an Air Contaminant (29 CFR 1910.1000, Table Z-1-A)

Section 8. Special Protection Data

Goggles: Wear protective eyeglasses or chemical safety goggles, per OSHA eye- and face-protection regulations (29 CFR 1910.133). Because contact lens use in industry is controversial, establish your own policy. **Respirator:** Seek professional advice prior to selection and use. Follow OSHA respirator regulations (29 CFR 1910.134) and, if necessary, wear a MSHA/NIOSH-approved respirator. For < 1000 ppm, use a powered air-purifying respirator with an appropriate organic vapor cartridge, a supplied-air respirator (SAR), SCBA, or chemical cartridge respirator with appropriate organic vapor cartridge. For < 2000 ppm, use a SAR or SCBA with a full facepiece. For emergency or nonroutine operations (cleaning spills, reactor vessels, or storage tanks), wear an SCBA. *Warning! Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.* If respirators are used, OSHA requires a respiratory protection program that includes at least: medical certification, training, fit-testing, periodic environmental monitoring, maintenance, inspection, cleaning, and convenient, sanitary storage areas. **Other:** Wear chemically protective gloves, boots, aprons, and gauntlets made of Viton or polyvinylchloride to prevent skin contact. **Ventilation:** Provide general and local exhaust ventilation systems to maintain airborne concentrations below the OSHA PELs (Sec. 2). Local exhaust ventilation is preferred because it prevents contaminant dispersion into the work area by controlling it at its source.[103] **Safety Stations:** Make available in the work area emergency eyewash stations, safety/quick-drench showers, and washing facilities. **Contaminated Equipment:** Separate contaminated work clothes from street clothes and launder before reuse. Remove this material from your shoes and clean PPE. **Comments:** Never eat, drink, or smoke in work areas. Practice good personal hygiene after using this material, especially before eating, drinking, smoking, using the toilet, or applying cosmetics.

Section 9. Special Precautions and Comments

Storage Requirements: Store in a cool, dry, well-ventilated area away from ignition sources and oxidizers. Outside or detatched storage is preferred. If inside, store in a standard flammable liquids cabinet. Containers should have flame-arrester or pressure-vacuum venting. To prevent static sparks, electrically ground and bond all equipment used with ethylbenzene. Install Class 1, Group D electrical equipment. **Engineering Controls:** To reduce potential health hazards, use sufficient dilution or local exhaust ventilation to control airborne contaminants and to maintain levels as low as possible. Purge and ventilate reaction vessels before workers are allowed to enter for maintenance or cleanup. **Administrative Controls:** Consider preplacement and periodic medical exams of exposed workers that emphasize the CNS, skin, blood, and respiratory system.

Transportation Data (49 CFR 172.101)

DOT Shipping Name: Ethylbenzene
DOT Hazard Class: 3
D No.: UN1175
DOT Packing Group: II
DOT Label: Flammable liquid
Special Provisions (172.102): T1

Packaging Authorizations
a) Exceptions: 173.150
b) Non-bulk Packaging: 173.202
c) Bulk Packaging: 173.242

Quantity Limitations
a) Passenger Aircraft or Railcar: 5L
b) Cargo Aircraft Only: 60 L

Vessel Stowage Requirements
a) Vessel Stowage: B
b) Other: —

MSDS Collection **References:** 26, 73, 100, 101, 103, 124, 126, 127, 132, 133, 136, 139, 140, 148, 153, 159, 162, 163, 164, 167, 168, 171, 176, 179

Prepared by: M Gannon, BA; **Industrial Hygiene Review:** D Wilson, CIH; **Medical Review:** W Silverman, MD

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Material Safety Data Sheets Collection:

Sheet No. 318
Xylene *(Mixed Isomers)*

Issued: 11/80 Revision: E, 9/92

Section 1. Material Identification

39

Xylene (Mixed Isomers) (C_8H_{10}) Description: The commercial product is a blend of the three isomers [*ortho*-(*o*-), *meta*-(*m*-), *para*-(*p*-)] with the largest proportion being *m*- xylene. Xylene is obtained from coal tar, toluene by transalkylation, and pseudocumene. Used in the manufacture of dyes, resins, paints, varnishes, and other organics; as a general solvent for adhesives, a cleaning agent in microscope technique; as a solvent for Canada balsam microscopy; as a fuel component; in aviation gasoline, protective coatings, sterilizing catgut, hydrogen peroxide, perfumes, insect repellants, pharmaceuticals, and the leather industry; in the production of phthalic anhydride, isophthalic, and terephthalic acids and their dimethyl esters which are used in the manufacture of polyester fibers; and as an indirect food additive as a component of adhesives. Around the home, xylene is found as vehicles in paints, paint removers, degreasing cleaners, lacquers, glues and cements and as solvent/vehicles for pesticides.

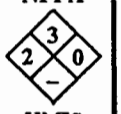
Other Designations: CAS No. 1330-20-7 [95-47-6; 108-38-3; 106-42-3 (*o*-, *m*-, *p*-isomers)], dimethylbenzene, methyltoluene, NCI-C55232, Violet 3, xylol.

Manufacturer: Contact your supplier or distributor. Consult latest *Chemical Week Buyers' Guide*[73] for a suppliers list.

Cautions: Xylene is an eye, skin, and mucous membrane irritant and may be narcotic in high concentrations. It is a dangerous fire hazard.

R	1
I	2
S	2
K	3

NFPA



HMIS
H 2†
F 3
R 0
PPE ‡
† Chronic Effects
‡ Sec. 8

Section 2. Ingredients and Occupational Exposure Limits

Xylene (mixed isomers): the commercial product generally contains ~ 40% *m*-xylene; 20% each of *o*-xylene, *p*-xylene, and ethylbenzene; and small quantities of toluene. Unpurified xylene may contain pseudocumene.

1991 OSHA PELs
8-hr TWA: 100 ppm (435 mg/m^3)
15-min STEL: 150 ppm (655 mg/m^3)

1990 IDLH Level
1000 ppm

1990 NIOSH RELs
TWA: 100 ppm (435 mg/m^3)
STEL: 150 ppm (655 mg/m^3)

1992-93 ACGIH TLVs
TWA: 100 ppm (434 mg/m^3)
STEL: 150 ppm (651 mg/m^3)
BEI (Biological Exposure Index): Methylhippuric acids in urine at end of shift: 1.5 g/g creatinine

1990 DFG (Germany) MAK
TWA: 100 ppm (440 mg/m^3)
Category II: Substances with systemic effects
Half-life: < 2 hr
Peak Exposure: 200 ppm, 30 min, average value, 4 peaks per shift

1985-86 Toxicity Data*
Human, inhalation, TC_{Lo}: 200 ppm produced olfaction effects, conjunctiva irritation, and other changes involving the lungs, thorax, or respiration.
Man, inhalation, LC_{Lo}: 10000 ppm/6 hr; toxic effects not yet reviewed.
Human, oral, LD_{Lo}: 50 mg/kg; no toxic effect noted.
Rat, oral, LD_{50}: 4300 mg/kg; toxic effect not yet reviewed.
Rat, inhalation, LC_{50}: 5000 ppm/4 hr; toxic effects not yet reviewed.

* See NIOSH, *RTECS* (XE2100000), for additional toxicity data.

Section 3. Physical Data

Boiling Point Range: 279 to 284 °F (137 to 140 °C)*
Boiling Point: *ortho:* 291 °F (144 °C); *meta:* 281.8 °F (138.8 °C); *para:* 281.3 °F (138.5 °C)
Freezing Point/Melting Point: *ortho:* -13 °F (-25 °C); *meta:* -53.3 °F (- 47.4 °C); *para:* 55 to 57 °F (13 to 14 °C)
Vapor Pressure: 6.72 mm Hg at 70 °F (21 °C)
Saturated Vapor Density (Air = 1.2 kg/m^3): 1.23 kg/m^3, 0.077 lbs/ft^3

Appearance and Odor: Clear, sweet-smelling liquid.

* Materials with wider and narrower boiling ranges are commercially available.

Molecular Weight: 106.16
Specific Gravity: 0.864 at 20 °C/4 °C
Water Solubility: Practically insoluble
Other Solubilities: Miscible with absolute alcohol, ether, and many other organic liquids.
Octanol/Water Partition Coefficient: logKow = 3.12-3.20
Odor Threshold: 1 ppm
Viscosity: <32.6 SUS

Section 4. Fire and Explosion Data

Flash Point: 63 to 77 °F (17 to 25 °C) CC	Autoignition Temperature: 982 °F (527 °C) (*m*-)	LEL: 1.1 (*m*-, *p*-); 0.9 (*o*-)	UEL: 7.0 (*m*-, *p*-); 6.7 (*o*-)

Extinguishing Media: For small fires, use dry chemical, carbon dioxide (CO_2), water spray or regular foam. For large fires, use water spray, fog or regular foam. Water may be ineffective. Use water spray to cool fire-exposed containers. **Unusual Fire or Explosion Hazards:** Xylene vapors or liquid (which floats on water) may travel to an ignition source and flash back. The heat of fire may cause containers to explode and/or produce irritating or poisonous decomposition products. Xylene may present a vapor explosion hazard indoors, outdoors, or in sewers. Accumulated static electricity may occur from vapor or liquid flow sufficient to cause ignition. **Special Fire-fighting Procedures:** Because fire may produce toxic thermal decomposition products, wear a self-contained breathing apparatus (SCBA) with a full facepiece operated in pressure-demand or positive-pressure mode. Structural firefighter's protective clothing will provide limited protection. If feasible and without risk, move containers from fire area. Otherwise, cool fire-exposed containers until well after fire is extinguished. Stay clear of tank ends. Use unmanned hose holder or monitor nozzles for massive cargo fires. If impossible, withdraw from area and let fire burn. Withdraw immediately in case of any tank discoloration or rising sound from venting safety device. Do not release runoff from fire control methods to sewers or waterways.

Section 5. Reactivity Data

Stability/Polymerization: Xylene is stable at room temperature in closed containers under normal storage and handling conditions. Hazardous polymerization cannot occur. Xylene is easily chlorinated, sulfonated, or nitrated. **Chemical Incompatibilities:** Incompatibilities include strong acids and oxidizers and 1,3-dichloro-5,5-dimethyl-2,4-imidazolidindione (dichlorohydrantoin). Xylene attacks some forms of plastics, rubber, and coatings. **Conditions to Avoid:** Avoid heat and ignition sources and incompatibles. **Hazardous Products of Decomposition:** Thermal oxidative decomposition of xylene can produce carbon dioxide, carbon monoxide, and various hydrocarbon products.

Section 6. Health Hazard Data

Carcinogenicity: The IARC,[164] NTP,[169] and OSHA[164] do not list xylene as a carcinogen. **Summary of Risks:** Xylene is an eye, mucous membrane, and respiratory tract irritant. Irritation starts at 200 ppm; severe breathing difficulties which may be delayed in onset can occur at high concentrations. It is a central nervous system (CNS) depressant and at high concentrations can cause coma. Kidney and liver damage can occur with xylene exposure. With prolonged or repeated cutaneous exposure, xylene produces a defatting dermatitis. Chronic toxicity is not well defined, but it is less toxic than benzene. Prior to the 1950s, benzene was often found as a contaminant of xylene and the effects attributed to xylene such as blood dyscrasias are questionable. Since the late 1950s, xylenes have been virtually benzene-free and blood dyscrasias have not been associated with xylenes. Chronic exposure to high concentrations of xylene in animal studies have demonstrated milk reversible decrease in red and white cell counts as well as increases in platelet counts.

Continue on next page

Section 6. Health Hazard Data, *continued*

irregularity was reported in association with workplace exposure to xylene perhaps due to effects on liver metabolism. Xylene crosses the human centa, but does not appear to be teratogenic under conditions tested to date. **Medical Conditions Aggravated by Long-Term Exposure:** CNS, piratory, eye, skin, gastrointestinal (GI), liver and kidney disorders. **Target Organs:** CNS, eyes, GI tract, liver, kidneys, and skin. **Primary Entry Routes:** Inhalation, skin absorption (slight), eye contact, ingestion. **Acute Effects:** Inhalation of high xylene concentrations may cause dizziness; nausea, vomiting, and abdominal pain; eye, nose, and throat irritation; respiratory tract irritation leading to pulmonary edema (fluid in lung); drowsiness; and unconsciousness. Direct eye contact can result in conjunctivitis and corneal burns. Ingestion may cause a burning sensation in the oropharynx and stomach and transient CNS depression. **Chronic Effects:** Repeated or prolonged skin contact may cause drying and defatting of the skin leading to dermatitis. Repeated eye exposure to high vapor concentrations may cause reversible eye damage, peripheral and central neuropathy, and liver damage. Other symptoms of chronic exposure include headache, fatigue, irritability, chronic bronchitis, and GI disturbances such as nausea, loss of appetite, and gas.

FIRST AID *Emergency personnel should protect against exposure.* **Eyes:** *Do not* allow victim to rub or keep eyes tightly shut. Gently lift eyelids and flush immediately and continuously with flooding amounts of water until transported to an emergency medical facility. Consult a physician immediately. **Skin:** *Quickly* remove contaminated clothing. Rinse with flooding amounts of water for at least 15 min. Wash exposed area with soap and water. For reddened or blistered skin, consult a physician. Carefully dispose of contaminated clothing as it may pose a fire hazard. **Inhalation:** Remove exposed person to fresh air and support breathing as needed. Monitor exposed person for respiratory distress. **Ingestion:** Never give anything by mouth to an unconscious or convulsing person. Contact a poison control center and unless otherwise advised, *do not induce vomiting!* If spontaneous vomiting should occur, keep exposed person's head below the hips to prevent aspiration (breathing liquid xylene into the lungs). *Aspiration of a few millimeters of xylene can cause chemical pneumonitis, pulmonary edema, and hemorrhage.* **Note to Physicians:** Hippuric acid or the ether glucuronide of *ortho*-toluic acid may be useful in diagnosis of *meta-*, *para-* and *ortho*-xylene exposure, respectively. Consider gastric lavage if a large quantity of xylene was ingested. Proceed gastric lavage with protection of the airway from aspiration; consider endotracheal intubation with inflated cuff.

Section 7. Spill, Leak, and Disposal Procedures

Spill/Leak: Notify safety personnel, evacuate all unnecessary personnel, remove all heat and ignition sources, and ventilate spill area. Cleanup personnel should protect against vapor inhalation and skin or eye contact. If feasible and without undue risk, stop leak. Use appropriate foam to blanket release and suppress vapors. Water spray may reduce vapor, but does not prevent ignition in closed spaces. For small spills, absorb on paper and evaporate in appropriate exhaust hood or absorb with sand or some non-combustible absorbent and place in containers for later disposal. For large spills dike far ahead of liquid to contain. Do not allow xylene to enter a confined space such as sewers or drains. On land, dike to contain or divert to impermeable holding area. Apply water spray to control flammable vapor and remove material with pumps or vacuum equipment. On water, contain material with natural barriers, booms, or weirs; apply universal gelling agent; and use suction hoses to remove spilled material. Report any release in excess of 1000 lb. Follow applicable OSHA regulations (29 CFR 1910.120). **Environmental Transport:** Little bioconcentration is expected. Biological oxygen demand 5 (after 5 days at 20 °C): 0.64 (no stated isomer). **Ecotoxicity values:** LD_{50}, Goldfish, 13 mg/L/24 hr, conditions of bioassay not specified, no specific isomer. **Environmental Degradation:** In the atmosphere, xylenes degrade by reacting with photochemically produced hydroxyl radicals with a half-life ranging from 1-1.7 hr. in the summer to 10-18 hr in winter or a typical loss of 67-86% per day. Xylenes are resistant to hydrolysis. **Soil Absorption/Mobility:** Xylenes have low to moderate adsorption to soil and when spilled on land, will volatilize and leach into groundwater. **Disposal:** As a hydrocarbon, xylene is a good candidate for controlled incineration. Contact your supplier a licensed contractor for detailed recommendations. Follow applicable Federal, state, and local regulations.

A Designations

SARA Extremely Hazardous Substance (40 CFR 355): Not listed
Listed as a SARA Toxic Chemical (40 CFR 372.65)
Listed as a RCRA Hazardous Waste (40 CFR 261.33): No. U239, F003 (spent solvent)
Listed as a CERCLA Hazardous Substance* (40 CFR 302.4): Final Reportable Quantity (RQ), 1000 lb (454 kg) [* per Clean Water Act, Sec. 311(b)(4); per RCRA, Sec. 3001]

OSHA Designations

Listed as an Air Contaminant (29 CFR 1910.1000, Table Z-1-A)

Section 8. Special Protection Data

Goggles: Wear protective eyeglasses or chemical safety goggles, per OSHA eye- and face-protection regulations (29 CFR 1910.133). Because contact lens use in industry is controversial, establish your own policy. **Respirator:** Seek professional advice prior to respirator selection and use. Follow OSHA respirator regulations (29 CFR 1910.134) and, if necessary, wear a MSHA/NIOSH-approved respirator. For concentrations >1000 ppm, use any chemical cartridge respirator with organic vapor cartridges; any powered, air-purifying respirator with organic vapor cartridges; any supplied-air respirator; or any self-contained breathing apparatus. For emergency or nonroutine operations (cleaning spills, reactor vessels, or storage tanks), wear an SCBA. *Warning! Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.* If respirators are used, **Other:** Wear chemically protective gloves, boots, aprons, and gauntlets to prevent all skin contact. With breakthrough times > 8 hr, consider polyvinyl alcohol and fluorocarbon rubber (Viton) as materials for PPE. **Ventilation:** Provide general and local exhaust ventilation systems to maintain airborne concentrations below the OSHA PELs (Sec. 2). Local exhaust ventilation is preferred because it prevents contaminant dispersion into the work area by controlling it at its source.[103] **Safety Stations:** Make available in the work area emergency eyewash stations, safety/quick-drench showers, and washing facilities. **Contaminated Equipment:** Separate contaminated work clothes from street clothes. Launder contaminated work clothing before wearing. Remove this material from your shoes and clean PPE. **Comments:** Never eat, drink, or smoke in work areas. Practice good personal hygiene after using this material, especially before eating, drinking, smoking, using the toilet, or applying cosmetics.

Section 9. Special Precautions and Comments

Storage Requirements: Store in clearly labelled, tightly closed, containers in a cool, well-ventilated place, away from strong oxidizing materials and heat and ignition sources. During transferring operations, electrically ground and bond metal containers. **Engineering Controls:** To reduce potential health hazards, use sufficient dilution or local exhaust ventilation to control airborne contaminants and to maintain concentrations at the lowest practical level. Use hermetically sealed equipment, transfer xylene in enclosed systems, avoid processes associated with open evaporating surfaces, and provide sources of gas release with enclosures and local exhaust ventilation. Use Class I, Group D electrical equipment. **Administrative Controls:** Establish air and biological monitoring programs and evaluate regularly. Consider preplacement and periodic medical examinations including a complete blood count, a routine urinalysis, and liver function tests. Consider hematologic studies if there is any significant contamination of the solvent with benzene. If feasible, consider the replacement of xylene by less toxic solvents such as petrol (motor fuel) or white spirit. Before carrying out maintenance and repair work, steam and flush all equipment to remove any xylene residues.

Transportation Data (49 CFR 172.101)

	Packaging Authorizations	Quantity Limitations	Vessel Stowage Requirements
DOT Shipping Name: Xylenes DOT Hazard Class: 3 No.: UN1307 DOT Packing Group: II DOT Label: Flammable Liquid Special Provisions (172.102): T1	a) Exceptions: 173.150 b) Nonbulk Packaging: 173.202 c) Bulk Packaging: 173.242	a) Passenger, Aircraft, or Railcar: 5L b) Cargo Aircraft Only: 60L	a) Vessel Stowage: B b) Other: –

MSDS Collection References: 26, 73, 89, 100, 101, 103, 124, 126, 127, 132, 133, 136, 139, 140, 148, 149, 153, 159, 163, 164, 167, 171, 174, 176, 180.
Prepared by: MJ Wurth, BS; Industrial Hygiene Review: PA Roy, MPH, CIH; Medical Review: W Silverman, MD

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Material Safety Data Sheets Collection:

Sheet No. 298
Jet Fuels

Issued: 8/90

Section 1. Material Identification

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Jet Fuel Description: A petroleum distillate similar to kerosine composed of C_5 to C_{16} aliphatics, monocyclo-paraffins, aromatics, and olefins (for turbine engines only). Aromatics are a lower percentage for jet fuels, but there are a number of jet fuel types with somewhat different compositions and properties.
Other Designations: Jet A, Jet A-1, Jet B, Jet fuel HEF-3, JP-1, JP-4, JP-5, JP-6.
Manufacturer: Contact your supplier or distributor. Consult the latest *Chemicalweek Buyers' Guide*[73] for a suppliers list.
Cautions: *Jet fuel is volatile, combustible, and thus, a dangerous fire hazard.* It is a skin, eye, and respiratory tract irritant. *Ingestion can be harmful, even fatal.*

(a) Jet A and Jet A-1 (combustible) and JP-5 (flammable to combustible).
(b) Jet B (dangerous fire hazard) and JP-4 (dangerous fire hazard and moderate explosion hazard in the form of vapor).

R 1
I -
S 2
K 2-4*
* Varying flash points

NFPA (a): 2 / 0 / 0 / -
NFPA (b): 3 / 1 / 0 / -

HMIS		HMIS	
H	1	H	1
F	2	F	3
R	0	R	0
PPG†		PPG†	

† Sec. 8

Section 2. Ingredients and Occupational Exposure Limits

Jet fuel, ca 100%

1989 OSHA PEL	1989-90 ACGIH TLV	1988 NIOSH REL	1985-86 Toxicity Data*
None established	None established	None established	Rat, oral, LD_{50}: 40 mg/kg Rat, inhalation, LC_{50}: 23 ppm/4 hr Rat, skin, LD_{50}: 317 mg/kg

* These toxicity data pertain to jet fuel HEF-3. See NIOSH, *RTECS* (MH5425100), for additional toxicity data.

Section 3. Physical Data*

Boiling Point: 300 to 550 °F (149 to 288 °C)
Vapor Pressure: 0.1 mm Hg at 20 °C
Viscosity: 1.0 to 2.0 cSt at 72 °F (40 °C)
Relative Density (15 °C/4 °C): 0.79 to 0.84
Water Solubility: Negligible

Appearance and Odor: A clear liquid with a hydrocarbon odor.

* Physical data vary with fuel type. These data pertain to kerosine jet fuels in general.

Section 4. Fire and Explosion Data

Flash Point: 100 °F (37.8 °C), OC*	Autoignition Temperature: 446 °F (230.2 °C)*	LEL: 0.6% v/v	UEL: 3.7% v/v
Jet A and Jet A-1: 110 to 150 °F (43.4 to 65.6 °C) Jet B: -16 to -30 °F (-26.7 to -34.5 °C) JP-1: 95 to 145 °F (35.0 to 62.8 °C) JP-4†: -10 to 30 °F (-23.4 to -1.1 °C) JP-5: 95 to 145 °F (35.0 to 62.8 °C)	JP-1: 442 °F (228 °C) JP-4: 468 °F (242 °C) JP-5: 475 °F (246 °C)	JP-4: 1.3% v/v	JP-4: 8.0% v/v

Extinguishing Media: For large fire, use water spray, fog, or foam. For small fires, use dry chemical or CO_2. Water may be ineffective in fighting fires involving materials with low flash points. Apply in the form of a spray.
Unusual Fire or Explosion Hazards: Jet fuel is volatile and combustible.
Special Fire-fighting Procedures: Since fire may produce toxic fumes, wear a self-contained breathing apparatus (SCBA) with a full facepiece operated in the pressure-demand or positive-pressure mode and full protective equipment. Be aware of runoff from fire control methods. Do not release to sewers or waterways.

*A higher kerosene cut than JP-4 with fewer impurities.
† 65% gasoline and 35% light petroleum distillate.

Section 5. Reactivity Data

Stability/Polymerization: Jet fuels are stable at room temperature in closed containers under normal storage and handling conditions. Hazardous polymerization cannot occur.
Chemical Incompatibilities: A violent reaction occurs with fluorine (F_2). Jet fuels are also incompatible with halogens, strong acids, alkalines, and oxidizers.
Conditions to Avoid: Avoid heat, sparks, flame, and build up of static electricity.
Hazardous Products of Decomposition: Thermal oxidative decomposition of jet fuel can produce carbon monoxide from incomplete combustion.

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APPENDIX B-5

VAPOR MONITORING FORMS

AIR MONITORING DATA									Today's Date:
Project/Task Name:					Project/Task Numbers:				
Form Completed By: (print name)					(signature)				(date)
Time	Location	Ionization Detector Reading		Explosimeter Reading		Other Instruments (detector tubes, dust monitor, etc.)			Comments
		FID	PID	%LEL	$\%O_2$	(type/units)	(type/units)	(type/units)	

AIR MONITORING DATA									Today's Date:
Project/Task Name:					Project/Task Numbers:				
Form Completed By: (print name)					(signature)				(date)
Time	Location	Ionization Detector Reading		Explosimeter Reading		Other Instruments (detector tubes, dust monitor, etc.)			Comments
		FID	PID	%LEL	$\%O_2$	(type/units)	(type/units)	(type/units)	

AIR MONITORING DATA									Today's Date:
Project/Task Name:					Project/Task Numbers:				
Form Completed By: (print name)					(signature)				(date)
Time	Location	Ionization Detector Reading		Explosimeter Reading		Other Instruments (detector tubes, dust monitor, etc.)			Comments
		FID	PID	%LEL	$\%O_2$	(type/units)	(type/units)	(type/units)	

AIR MONITORING DATA									Today's Date:
Project/Task Name:					Project/Task Numbers:				
Form Completed By: (print name)					(signature)				(date)
Time	Location	Ionization Detector Reading		Explosimeter Reading		Other Instruments (detector tubes, dust monitor, etc.)			Comments
		FID	PID	%LEL	$\%O_2$	(type/units)	(type/units)	(type/units)	

AIR MONITORING DATA									Today's Date:
Project/Task Name:					Project/Task Numbers:				
Form Completed By: (print name)					(signature)				(date)
Time	Location	Ionization Detector Reading		Explosimeter Reading		Other Instruments (detector tubes, dust monitor, etc.)			Comments
		FID	PID	%LEL	$\%O_2$	(type/units)	(type/units)	(type/units)	

AIR MONITORING DATA									Today's Date:
Project/Task Name:					Project/Task Numbers:				
Form Completed By: (print name)					(signature)				(date)
Time	Location	Ionization Detector Reading		Explosimeter Reading		Other Instruments (detector tubes, dust monitor, etc.)			Comments
		FID	PID	%LEL	$\%O_2$	(type/units)	(type/units)	(type/units)	

APPENDIX B-6

FIELD CALIBRATION LOGS

DAILY AIR MONITORING INSTRUMENT CALIBRATION & REFERENCE STANDARD CHECKS

Project/Task Name: **Project/Task Numbers:**

Form Completed By: (print name) (signature) (date)

DATE	TIME	AIR MONITORING INSTRUMENT			BATTERY CHECK		REFERENCE (SPAN) GAS		UNADJUSTED INSTRUMENT READING	CALIBRATION	
		TYPE	LAMP eV	SERIAL #	OK	LOW	TYPE	CONCENTRATION		OK	ADJUSTMENT REQ'D

COMMENTS:

DAILY AIR MONITORING INSTRUMENT CALIBRATION & REFERENCE STANDARD CHECKS

Project/Task Name: **Project/Task Numbers:**

Form Completed By: (print name) (signature) (date)

DATE	TIME	AIR MONITORING INSTRUMENT			BATTERY CHECK		REFERENCE (SPAN) GAS		UNADJUSTED INSTRUMENT READING	CALIBRATION	
		TYPE	LAMP eV	SERIAL #	OK	LOW	TYPE	CONCENTRATION		OK	ADJUSTMENT REQ'D

COMMENTS:

DAILY AIR MONITORING INSTRUMENT CALIBRATION & REFERENCE STANDARD CHECKS

Project/Task Name: **Project/Task Numbers:**

Form Completed By: (print name) (signature) (date)

DATE	TIME	AIR MONITORING INSTRUMENT			BATTERY CHECK		REFERENCE (SPAN) GAS		UNADJUSTED INSTRUMENT READING	CALIBRATION	
		TYPE	LAMP eV	SERIAL #	OK	LOW	TYPE	CONCENTRATION		OK	ADJUSTMENT REQ'D

COMMENTS:

DAILY AIR MONITORING INSTRUMENT CALIBRATION & REFERENCE STANDARD CHECKS

Project/Task Name: **Project/Task Numbers:**

Form Completed By: (print name) (signature) (date)

DATE	TIME	AIR MONITORING INSTRUMENT			BATTERY CHECK		REFERENCE (SPAN) GAS		UNADJUSTED INSTRUMENT READING	CALIBRATION	
		TYPE	LAMP eV	SERIAL #	OK	LOW	TYPE	CONCENTRATION		OK	ADJUSTMENT REQ'D

COMMENTS:

DAILY AIR MONITORING INSTRUMENT CALIBRATION & REFERENCE STANDARD CHECKS

Project/Task Name: **Project/Task Numbers:**

Form Completed By: (print name) (signature) (date)

DATE	TIME	AIR MONITORING INSTRUMENT			BATTERY CHECK		REFERENCE (SPAN) GAS		UNADJUSTED INSTRUMENT READING	CALIBRATION	
		TYPE	LAMP eV	SERIAL #	OK	LOW	TYPE	CONCENTRATION		OK	ADJUSTMENT REQ'D

COMMENTS:

DAILY AIR MONITORING INSTRUMENT CALIBRATION & REFERENCE STANDARD CHECKS

Project/Task Name: **Project/Task Numbers:**

Form Completed By: (print name) (signature) (date)

DATE	TIME	AIR MONITORING INSTRUMENT			BATTERY CHECK		REFERENCE (SPAN) GAS		UNADJUSTED INSTRUMENT READING	CALIBRATION	
		TYPE	LAMP eV	SERIAL #	OK	LOW	TYPE	CONCENTRATION		OK	ADJUSTMENT REQ'D

COMMENTS:

APPENDIX C

OPERATIONS INFORMATION

APPENDIX C-1

JOB SAFETY ANALYSIS

JOB SAFETY ANALYSIS
VEHICLE OPERATIONS

JOB STEPS - Vehicle Operations	
JOB HAZARDS	**CONTROL/SAFEGUARDS**
1. Employee run over or hit by moving vehicle	1. a. back up signals on equipment; b. traffic safety vest for all field personnel; c. foot traffic restricted in areas of operation; d. establish standard hand signals for laborers assisting in vehicle operations. e. turn off engine when leaving the vehicle.
2. Physical hazards; a. hit in head b. foreign body in eye c. foot injury	2. a. hard hat; b. safety glasses c. steel toe boots
3. Overhead utilities/overhead obstacles	3. Minimum 20' distance, 10' distance if insulated

JOB SAFETY ANALYSIS
SOIL GAS SURVEY

JOB STEPS - Soil gas survey using Geo-Probe Drill Rig	
JOB HAZARDS	**CONTROL/SAFEGUARDS**
1. Noise levels exceeding the OSHA personal exposure limit (PEL).	1. Utilize earmuffs and/or ear plugs to effectively reduce noise levels.
2. Vapors from suspect contaminants.	2. a. Review hazard information/MSDS for the contaminants suspected to be on-site; b. Perform required air monitoring; c. Redirect exhaust fumes; if action levels are approached; d. Reposition to upwind location. e. Shut down Geo-Probe Unit if action levels are exceeded; and f. No smoking in work zone.
3. Underground pipelines and utility lines can be ruptured or damaged during active drilling operations.	3. a. Have a dig-safe search conducted; b. Obtain as built plans or blueprints to identify underground utilities/obstacles; and c. Hand dig to 5' depth in questionable areas or suspect utilities.
4. Moving parts such as the sampling rod on the unit may catch clothing.	4. a. Secure loose clothing; b. Do not wear reflective vest; c. Check "kill switch" daily; and d. Keep hands free from moving parts.
5. High pressure hydraulic lines and air lines used on Geo-Probe Unit are hazardous when they are in need of repair or improperly assembled.	5. All high pressure lines should have preventative maintenance check regularly in accordance with manufacturer's recommendations.

JOB SAFETY ANALYSIS

DRILLING

JOB STEPS - Soil Boring\Drilling with Hollow-Stem Augers	
JOB HAZARDS	**CONTROL/SAFEGUARDS**
1. Noise levels exceeding the OSHA PEL	1. Earmuffs and/or ear plugs effectively reduce noise levels
2. Fumes from drilling rig; vapors from suspect contaminants	2. a. Review hazard information/MSDS for the contaminants suspected to be on-site and; b. Perform required air monitoring; c. Redirect exhaust fumes; if action levels are approached; d. Reposition to upwind location. e. Shut down drill rig if action levels are Exceeded; f. No smoking in work zone.
3. Overhead Utilities	3. a. Lower boom prior to moving drill rig; b. maintain 20' minimum distance; c. 10' distance if insulated or blanketed with cover or shroud. placed by utility firm representatives
4. Underground pipelines and utility lines can be ruptured or damaged during active drilling operations	4. a. have a dig-safe search conducted; b. obtain as built plans or blueprints to identify underground utilities/obstacles; c. hand dig to 5' depth in questionable areas or suspect utilities.
5. Free or falling parts from the cat head may cause head injury	5. a. wear head protection; b. inspect wires, cables and ropes; c. do not raise/hoise objects or stack piping greater than 1 foot above the crown block heights.
6. Moving parts such as augers on the rig may catch clothing	6. a. secure loose clothing; b. do not wear reflective vest; c. check "kill switch" daily; d. keep hands free from moving parts.
7. High pressure hydraulic lines and air lines used on drill rigs are hazardous when they are in need of repair or improperly assembled.	7. All high pressure lines should have preventative maintenance check regularly
8. Lack of rig stability, failure stabilizing plates (jacks or out riggers) or tilt from high winds -- tip over, roll over or collapse.	8. a. establish safe work zone; b. choose level ground; c. engage emergency brake.
9. Unattended borehole, trip and fall hazard.	9. a. Cover or protect well head or borehole location to prevent equipment, personnel, visitors or animals from stepping or falling into the hole.

JOB SAFETY ANALYSIS

BIOVENT PILOT TEST

JOB STEPS - Biovent pilot test	
JOB HAZARDS	**CONTROL/SAFEGUARDS**
CONSTRUCTION 1. Injury due to improper assembly of PVC piping system a. PVC pipe burst due to pressure b. PVC pipe fittings break loose under pressure c. Pressure causes bulges or system leaks	1. a. Verify pipe rating is sufficient for design/operating pressures b. Following Manufacturers' cleaning and gluing procedures regarding proper application and drying times c. Install appropriate gauges, high pressure shutoffs and pressure relief valves.
2. Exposure to PVC primer and glue	2. a. Use in well ventilated area. b. Avoid dermal contact. Wear gloves if necessary.
3. (Back) Injury due to lifting or moving heavy objects	3. Always bend at the knees when lifting heavy objects. Keep the weight close to your body. Do not twist or turn the body while lifting awkward shaped objects or objects too heavy to lift comfortably alone.
OPERATION/MAINTENANCE 1. a. Fuel refilling - hot surface hazard. b. Noise/sound hazard	1. a. Shut off and allow to cool before refueling; no smoking b. Monitor sound with sound level meter for personal and community noise exposure; wear PPE
2. Implementation of Bioventing Pilot test (i.e. burst of pipes upon start up, leak of pipes, noise)	2. a. Allow pressure to build slowly to test lines; shield accordingly; provide distance b. Wear goggles; faceshield as necessary c. Wear PPE; insulate and provide distance
3. Electric Shock, troubleshooting blowers, changing filters, gauges, etc.	1. a. Installation shall be such that a separate circuit which can be locked and tagged out is installed.Lockout/tagout procedures must be followed. Prior to conducting any equipment maintenance, the system must be deenergized and locked and tagged out. b. GFCIs must be used with all hand tools. c. Only designated and trained personnel may troubleshoot electrical equipment with amp/volt meters.

SITE-SPECIFIC LOCKOUT/TAGOUT PROCEDURES - This sheet shall be updated immediately if additional equipment is brought on site.

SITE-SPECIFIC LOCKOUT/TAGOUT PROCEDURES		
Equipment	**Operation**	**Lockout Method/Location**
1.Bioventing Blower		1. Lockout at circuit breaker box. Pull handle down, lock, and tag such that circuit cannot be reenergized.
2. Hand tools	Construction/repair of equipment/piping	2. a. GFCI must be used during normal operation. b. Remove extension cords, tag plug end. If repair of hand tools is required, it must be performed by designated personnel.

APPENDIX C-2

SITE SPECIFIC LOCKOUT/TAGOUT PROCEDURES AND GROUNDWATER TECHNOLOGY LOCKOUT/ TAGOUT PROGRAM

GROUNDWATER TECHNOLOGY, INC.
HEALTH & SAFETY POLICY & PROCEDURE No. 13

LOCKOUT/TAGOUT PROGRAM

1.0 PURPOSE

This document outlines the Lockout/Tagout Program and requirements for employees to do work and maintenance requiring isolation of electrical driven equipment, pneumatics, liquid pipelines, mechanical equipment, steam and hydraulic systems.

2.0 POLICY

Managers shall assure capability of isolation control (Lockout/Tagout) for safe working conditions with employees engaged in installation, repair, maintenance and trouble shooting of equipment.

3.0 RESPONSIBILITIES

The responsibilities and rules are described:

MANAGER: Shall assure by inspection and audit of sites and facilities that isolation equipment is available, technical staff trained in its use, and general practice utilizes isolation controls.

TRAINER: Shall be qualified and trained to give instruction on hazards, equipment to be utilized and practice guidelines to follow.

HEALTH & SAFETY REPRESENTATIVES:

Shall assist managers in assuring isolation equipment is readily available, technical staff trained to operate safely; general practice utilizes equipment, forms and documented and proper safe behaviors employed.

AUTHORIZED EMPLOYEE:

Shall be trained and qualified to administer and apply Lockout/Tagout isolation devices as part of their safe work practices.

4.0 PROGRAM ELEMENTS

This program is intended to outline the requirements for applying isolation technique and controls to achieve safe work conditions (Lockout/Tagout):

4.1 Management responsibility is critical for an effective lockout/tagout program. Managers should assure procedures are documented, have written supervisory and enforcement duties and includes disciplinary action to be taken when procedures are not followed.

5.0 ADDENDUM

6.0 Types of Hazards that Injure Employees
7.0 Lockout/Tagout Required
8.0 Initial Training Elements
9.0 Acceptable Application of Isolation
10.0 Procedures for Application
11.0 Procedures for Piping Systems
12.0 Specific Use of Lockout/Tagout Control Devices
13.0 Types of Energy That Must Be Controlled
14.0 Authorized Employees
15.0 Manager's Required Steps
16.0 Protective Materials and Hardware
17.0 Required Training for Authorized Employees
18.0 Application of Energy Controls
19.0 Basic Rules for Lockout/Tagout
20.0 Outline of Plan for Lockout Procedure for Each Office
21.0 References
Exhibit "A" Methods and Procedures for Lockout/Tagout
Exhibit "B" Project Site Lockout/Tagout Worksheet
Exhibit "C" Lockout/Tagout Plan Elements
Exhibit "D" Lockout/Tagout Emergency Lock Removal Form
Exhibit "E" Examples of Hazard Marking Tags and Lockout Equipment
Exhibit "F" Sample Policy and Procedure Notice
Exhibit "G" Possible Locations for Lockout/Tagout

6.0 TYPES OR HAZARDS THAT INJURE EMPLOYEES

6.1 Failure to de-energize machine or control energy
6.2 Accidental re-energization while working on equipment
6.3 Ineffective energy isolation, controls slipped off
6.4 Disregard for residual energy, stored energy hurt employee
6.5 Types tasks being performed at the time of the accident:

6.5.1 Unjamming object, cleaning equipment, repairing equipment, adjusting equipment, doing setup work, inspecting equipment, testing equipment, installing equipment and electrical work

7.0 LOCKOUT/TAGOUT REQUIRED BECAUSE CLEARLY SIMPLY CLOSING DOWN OR SHUTTING OFF MACHINERY IS INSUFFICIENT WHEN REPAIRING, MAINTAINING OR SERVICING EQUIPMENT.

8.0 INITIAL TRAINING ON LOCKOUT/TAGOUT PROCEDURES SHOULD COVER ELEMENTS UTILIZING:

8.1 Printed instructions
8.2 Procedures posted on equipment
8.3 Practical hands-on utilization of isolation equipment
8.4 Training provided during job orientation
8.5 Ongoing refresher training repeated at least annually

9.0 THE ONLY ACCEPTABLE AND SECURE APPLICATION OF ISOLATION IS THE USE OF LOCKS WHICH PROVIDE POSITIVE RESTRAINT.

10.0 THE PROCEDURES FOR APPLICATION AND REQUIRED STEPS FOR SAFE PERFORMANCE AND MAINTENANCE (ACCORDING TO 1910.147) ARE:

10.1 Equipment shutdown
10.2 Isolation
10.3 Lockout/Tagout application
10.4 Stored energy restrictions
10.5 Verification

11.0 FOR PIPING SYSTEMS, THE PROCEDURAL STEPS MAY BE:

11.1 Deactivation
11.2 Removing Contents
11.3 Isolation
11.4 Decontamination
11.5 Restraining
11.6 Verification
11.7 Control
11.8 Communication

In this case, OSHA will consider bolted blank flanges or slip blinds to be acceptable lockout/tagout.

12.0 SPECIFIC USE OF LOCKOUT/TAGOUT OR OTHER ENERGY CONTROL DEVICES FOR CERTAIN MACHINES AND EQUIPMENT MAY REQUIRE THE USE OF LOCKS, LOCKS/TAGS, AND IN SOME CASES, THE USE OF BLOCKS TO CONTROL POTENTIALLY HAZARDOUS ENERGY.

12.1 Example of electrical control is the main switch shall be open and locked in open position.

12.2 When cleaning, inspecting, or work requiring an employee to enter the working parts, all control devices shall be locked and tagged out.

12.3 Valves controlling lines or pipelines leading into a space to be occupied by an employee shall be locked out and tagged; keys to the locks shall be in possession of the person entering the space, making repairs, or doing maintenance.

12.4 Safety blocks shall be used to prevent employees from being crushed as in repair of presses or doing work in elevator shafts.

12.5 Authorized Employee: A qualified person to whom the authority and responsibility has been given to perform lockout/tagout assignments by Groundwater Technology. This employee must utilize the energy control procedures as part of their job and develop and maintain the knowledge and skills needed for safe application and removal of energy controls.

12.6 Affected Employee: An employee who must be trained to recognize when the energy control is being implemented, to be able to identify locks and tags being used, understand the importance and purpose of not removing or attempting to start up equipment which has been locked or tagged off.

13.0 TYPES OF ENERGY THAT MUST BE CONTROLLED:

13.1 Mechanical motion which can be linear or rotation and can produce work

13.2 Mechanical energy which can produce changes in temperature

13.3 Potential energy that can be pressure and be above or below atmospheric pressure (e.g., hydraulic, pneumatic or vacuum systems)

13.4 Potential energy manifested in pressure or springs needs to be dissipated or controlled release because it cannot be turned on or off.

13.5 Electrical energy is either generated or static electricity:

Electric generated power can be turned off.
Static electricity cannot be turned off so it requires dissipation or controlled release.

13.6 Thermal energy is manifested in high or low temperature. This energy is the result of:

13.6.1 Mechanical Energy
13.6.2 Radiation
13.6.3 Chemical Reaction
13.6.4 Electrical Resistance

It cannot be turned on or off but can be dissipated.

14.0 AUTHORIZED EMPLOYEES ARE RESPONSIBLE FOR THE REMOVAL OF LOCKOUT/TAGOUT DEVICES. THE FOLLOWING STEPS MUST BE TAKEN PRIOR TO THAT REMOVAL:

14.1 The machine or equipment is returned to effective operating condition.

14.2 All affected and authorized employees are notified of controls removal.

14.3 Authorized employees follow procedures for safe removal.

15.0 MANAGER'S REQUIRED STEPS TO LIMIT EXPOSURES TO EMPLOYEES

15.1 Verification of shutdown before employees can place personal lockout devices or energy isolating devices on the lockout box, board or cabinet.

15.2 Ensure all employees have completed their assignments, removed their lockout devices, or are in the clear before turning equipment or machinery on.

15.3 Provide necessary coordinating procedures for safe transfer of lockout/tagout control devices between other groups or other work shifts.

16.0 PROTECTIVE MATERIALS AND HARDWARE

16.1 Locks, tags, chains, wedges, key blocks, adaptor pins, self-locking fasteners, or other hardware (see Exhibit A) used for isolating, securing, or blocking of equipment from energy sources.

16.2 Tagout devices shall be constructed and printed so that exposure to weather conditions or damp locations will not cause deterioration or make the message illegible.

16.3 Tagout devices shall warn against hazardous conditions if the machine or equipment is energized. The legend shall read:

16.3.1 Do Not Start
16.3.2 Do Not Open
16.3.3 Do Not Close
16.3.4 Do Not Energize
16.3.5 Do Not Operate

17.0 REQUIRED TRAINING FOR AUTHORIZED EMPLOYEES INCLUDES:

17.1 Purpose and function of the program understood by employee.

17.2 Knowledge and skills required for safe application, use, and removal of energy controls.

17.3 Recognition of hazard energy sources and methods and means of control.

17.4 Instructed in use of energy controls.

17.5 Limitations of tags: Do not remove physical restraint.

17.6 Tags must be durable, understood and well attached.

17.7 Changes in jobs require re-training where energy controls change.

17.8 Employee training shall be certified and documented with updates and refreshers documented. The certification shall contain each employee's name and dates of training.

17.9 Implementation and documentation of lockout/tagout systems shall only be performed by authorized employees.

18.0 APPLY ENERGY CONTROLS

Energy isolation and lockout/tagout are to be applied only by trained authorized employees. Before lockout/tagout is applied, all employees who work in the affected area must be notified. The OSHA regulation requires the following sequence:

18.1 Preparation for Shutdown:

- Know the types and amounts of energy that power it.
- Know the hazards of that energy.
- Know how the energy can be controlled.

18.2 Equipment Shutdown:

- Shut equipment down using its operating controls.
- Follow the equipment procedure

18.3 Equipment Isolation:

- Operate all energy isolating devices so that equipment is isolated from its energy sources.
- Be sure to isolate all energy sources - secondary power as well as the main power supply.
- Never pull an electrical switch while it is under load.
- Never remove a fuse instead of disconnecting.

18.4 Applying Lockout/Tagout Devices

- All energy isolating devices are to be locked and tagged in compliance with OSHA and Groundwater Technology standards.
- Only the standardized lockout devices are to be used for lockout/tagout procedures and this equipment shall not be used for other purposes.
- A lockout device must be used if the lock cannot be applied directly to the energy control.
- When lockout is used, every employee in the work crew shall have his own lock attached to the multiple lockout hasp.
- Tags must accompany the lockout device and shall be filled out completely and correctly (See Exhibit E).

18.5 Control of Stored Energy:

This method is necessary to guard against energy that may be left in equipment after it has been isolated from the energy source.

- Authorized employee shall inspect the system to make sure all parts have stopped moving.
- Install ground wires to the equipment.
- Relieve trapped pressure in lines and equipment.
- Release tension pressure on springs or spring-driven parts.
- Block or brace parts that may fall because of gravity.
- Block and secure parts in both hydraulic and pneumatic equipment systems that could move or fall from loss of pressure.
- Bleed all hydraulic and pneumatic lines and leave the vent valves open.
- Drain all process piping systems and close valves to prevent the flow of hazardous materials back into the lines.
- If a line must be blocked, but there is no valve, use a blank flange.
- Purge all reactor tanks and process lines leading into the tanks.
- Dissipate extreme cold or heat and wear proper protective clothing.
- If stored energy can re-accumulate during the repair or maintenance session, monitor it to make sure it stays below hazardous levels. Check the pressure gauges regularly.

18.6 Verify the isolation of the equipment. Be sure you understand the equipment and the energy controls for the equipment.

- Make sure all personnel are clear of the danger areas.
- Verify the main disconnect switch or circuit breakers cannot be moved to the "on" position.
- Use a volt meter or other electrical meter to verify and check the switch.
- Press all start buttons and other activating controls on the equipment, try to move control levers and arms, and turn valves to assure they cannot be activated.
- Shut off all machine controls when your verification testing is completed.

18.7 Perform the Work

- Always be alert, look ahead, and avoid doing activities that could reactivate the equipment.
- Do not bypass the lockout guards when you repair piping or install new wiring.

18.8 Removing Lockout/Tagout

- Make sure the equipment is safe to operate.
  - Remove all tolls from the work area.
  - Be sure the system is fully assembled.
- Safeguard the employees.
  - Conduct a head count; make sure everyone is clear of the equipment.
  - Notify all employees and subcontractors in the area that lockout/tagout is being removed.
- Except in emergencies, the lockout device must be removed by the person who put it on.
- When the worker who applied the lock is not there to remove it:
  - The lock can only be removed in an emergency and only by direction of an authorized supervisor.
  - A lock can only be cut off with the authorized supervisor present.
  - Never remove a lock unless making sure it is absolutely safe to do so.
  - Fill out correctly and completely the lockout removal form and file it with the office manager (See Exhibit D).

19.0 BASIC RULES FOR LOCKOUT OR TAGOUT SYSTEM PROCEDURE

All equipment shall be locked out or tagged our to protect against accidental or inadvertent operation when such operation could cause injury to personnel. Do not attempt to operate any switch, valve or other energy isolating device where it is locked or tagged out.

20.0 OUTLINE OF PLAN FOR LOCKOUT PROCEDURE FOR EACH OFFICE

20.1 Groundwater Technology, Inc.
20.2 Types and magnitude of energy and hazards
20.3 Names and titles of employees who are authorized to do lockout/tagout
20.4 Names/job titles of affected employees and how to notify in case of lockout/tagout in their area
20.5 Types and location of energy isolating means for each site (See Exhibit B)
20.6 Type(s) of stored energy--methods to dissipate or restrain
20.7 Methods selected (i.e., locks, tags, additional safety measures)
20.8 Type(s) of equipment. Check to ensure disconnection.
20.9 Names(s) of employees authorized to do group lockout/tagout activities

21.0 REFERENCES

To comply with the following rgulations:

21.1 29 CFR 1910.147 Control of Hazardous Energy

21.2 Other Lockout/Tagout General Industry Standards

29 CFR 1910.178 Powered Industrial Truck
29 CFR 1910.179 Overhead and Gentry Cranes
29 CFR 1910.181 Derricks
29 CFR 1910.213 Woodworking Machinery
29 CFR 1910.217 Mechanical Power Presses
29 CFR 1910.218 Forging Machines
29 CFR 1910.522 Welding, Cutting and Brazing
29 CFR 1910.399 Electrical

21.3 If guards are removed (1910.212) from equipment, guarding or power transmission apparatus (1910.219) is required.

EXHIBIT A

Methods and Procedures for

Lockout/Tagout

DRAFT

ENERGY CONTROL (LOCKOUT/TAGOUT) PROCEDURES AND ELECTRICAL SAFETY-RELATED WORK PRACTICES

1.0 PURPOSE

1.1 To establish the minimum procedures for isolating mechanical or electrical equipment before repair, replacement, inspection, or testing.

1.2 To prevent injury to employees performing repair, maintenance, inspection, or testing on equipment where the unexpected energization, start-up, or release of stored energy could cause injury.

1.3 To prevent injury to employees due to unsafe electrical work practices during construction.

1.4 To comply with the following OSHA regulations

1.4.1 29 CFR 1910.147 Control of hazardous energy

1.4.2 Safety-Related Work Practices

29 CFR 1910.331	Scope.
29 CFR 1910.332	Training.
29 CFR 1910.333	Selection and use of work practices.
29 CFR 1910.334	Use of Equipment.
29 CFR 1910.335	Safeguards for personnel protection.

2.0 SCOPE

2.1 These procedures apply to all Groundwater Technology, Inc. (GTI) employees.

2.2 When performing work at a site at which the client requires procedures to be more stringent than those presented here, the client's procedures in force at that site supersede these procedures.

2.3 When several contractors or independent parties are working on the same site, each shall inform the others of their lockout/tagout procedures.

DRAFT

3.0 RESPONSIBILITY

3.1 The Regional Health and Safety Manager or their designee is responsible for scheduling employee training for energy control procedures and safe work practices within the respective region. They are also responsible for maintaining records to document initial training and any refresher training as necessary.

3.2 The District Manager or their designee is responsible for insuring individual locks and keys are provided to personnel assigned to operate, repair and maintain equipment within the respective region.

3.3 Project Managers are responsible for insuring that employees assigned the task of repairing and maintaining equipment fully understand the reason for these procedures and the necessity of compliance.

3.4 All employees are responsible for adhering to these procedures and shall notify their coworkers when observed using unsafe work practices. When a co-worker is notified they are using unsafe work practices but fails to respond, the employee shall notify their supervisor.

4.0 LOCKOUT/TAGOUT EQUIPMENT

4.1 Locks

4.1.1 Locks shall be substantial enough to require excessive force or bolt cutters to remove. Minimum shackle dimensions shall be 1½-inches high, ¼-inch diameter.

4.1.2 Locks shall not be keyed alike nor shall there be duplicate keys or master keys.

4.1.3 Case shall be red anodized aluminum.

4.1.4 American Lock Company, Model 1106R.

4.1.4.1 Available from Orr Safety Equipment Company, stock item.

4.1.4.2 Available from Grainger, Stock No. 1U246.

4.2 Multiple lock adapters

4.2.1 Double interlocking tabs to prevent prying open.

4.2.2 Aluminum construction, round hasp with a red polyester resin coating on the lock area.

4.2.3 Accommodate up to six locks of 3/8-inch maximum shackle diameter.

4.2.4 American Lock Company, 1-inch diameter hasp Model LO80, 1½-inch diameter hasp Model LO802.

4.2.4.1 Available from Orr Safety Equipment Company, stock item.

4.2.4.2 Available from Grainger, Stock No. 1U262 and Stock No. 1U263.

4.3 Tags

4.3.1 Plastic laminated or all plastic tag that is resistant to moisture, oil, dirt, corrosion, and tearing.

4.3.2 Metal grommeted attachment hole.

4.3.3 Nominal size, 3-inches by 6-inches by 0.025-inches thick.

4.3.4 One side of tag shall read "DANGER - DO NOT OPERATE" with lines for name and date. The other side shall read "DANGER - DO NOT REMOVE THIS TAG - SEE OTHER SIDE".

4.3.5 IDESCO Corporation, Model T 1-30.

4.3.5.1 Available from Orr Safety Equipment Company, stock item.

4.4 Tag Attachments

4.4.1 Molded nylon lock straps, also known as cable or wire ties.

4.4.2 Widely available from Grainger, electrical supply houses, and hardware stores.

4.5 Circuit Breaker Handle Padlock Attachment

4.5.1 Pad-lockable attachment for circuit breakers to lock them in the "off" position.

4.5.2 Attachment shall be designed to fit specific breakers used in the panelboard.

4.5.3 Manufacturers and catalog numbers.

4.5.3.1 Square D catalog number QO1PA for single pole breakers, catalog number QO1HPL for 2 and 3-pole breakers.

5.0 LOCKOUT/TAGOUT PROCEDURES

5.1 General

5.1.1 These procedures are to be used in conjunction with Section 6.0 Isolation Procedures to insure that once properly isolated, the equipment will not be inadvertently re-energized during the work procedures.

5.1.2 It is imperative that isolation devices be locked out, not merely tagged out. The tag out procedure is to be used alone only when it is not possible to lock out the device.

5.2 Application of Locks and Tags

5.2.1 A lock and tag shall be placed on each disconnecting means that is used to de-energize or isolate equipment.

5.2.2 Each employee working on the equipment shall apply their own lock and tag to the disconnecting means. A multiple lock adapter shall be used when more than one lock is to be applied.

5.2.3 When different shift crews are required to perform the work, the incoming shift workers shall attach their locks before the relieved workers remove theirs; the disconnecting means is never without a lock installed. At the beginning of each shift, the supervisor(s) should check the system lockout to assure the continued safety of employees.

5.2.4 At some sites where maintenance work is begun by one technician and finished by another, the following procedure may be used to prevent both technicians from travelling to the job site to transfer locks.

5.2.4.1 A multiple lock adapter shall be attached to the disconnecting means or isolating device so that multiple locks may be attached.

5.2.4.2 A tag and lock keyed for the site master key shall be attached and shall remain in place until the work is completed.

5.2.4.3 Each technician arriving on site to work on the equipment shall attach their individual lock and tag to the lock adapter with the master lock and tag. Upon leaving the site, the technician(s) shall remove their individual locks and tags, but leave the master lock and tag in place.

5.2.4.4 The technician who completes the work shall remove both his lock and tag and the master lock and tag and place the equipment back in service.

5.3 Removal of Locks and Tags

Before energy is restored to the equipment, ensure that the following steps are taken.

5.3.1 Inspect the work area to verify that all nonessential items have been removed and that the equipment is ready to be re-energized.

5.3.2 Check that all belts, belt guards, machine guards, and insulators are in place and properly positioned prior to energizing the equipment.

5.3.3 Notify affected employees and check to ensure that they are safely positioned prior to re-energizing the equipment.

5.3.4 Each lockout and tagout device is to be removed only by the person who applied the device. See 5.5 for the exception to this requirement.

5.4 Group Lockout/Tagout

5.4.1 When several contractors or other independent parties need to isolate a piece of equipment, they shall notify the project manager. The project manager shall be responsible for providing a group lockout/tagout device for this purpose.

5.4.2 The project manager shall assign responsibility for coordinating the placement, removal, or replacement of the group lockout/tagout device.

5.4.3 Each contractor or independent party shall use their own identifiable lock or tag on the group lockout/tagout device.

5.4.4 The last contractor or independent party to complete work shall notify the site manager or his designee that the group lockout/tagout can be removed. The contractor, with the concurrence of the project manager, shall then remove the group lockout/tagout device and energize the equipment.

5.4.5 When different work shift crews are required, the project manager shall designate an individual to carry out the coordination of the group lockout/tagout device as outlined above.

5.5 Exceptions or Special Conditions for Lock or Tag Removal

In the event the party who installed a lockout/tagout device is absent and it becomes necessary to remove the device to energize the equipment, the project manager, or their designee may, remove the lockout/tagout device, providing the following procedures are followed.

5.5.1 Verify, through reasonable means, the party's absence.

5.5.2 Make reasonable effort to notify the party that the lockout/tagout device will be removed.

5.5.3 Make the party aware that the lockout/tagout device has been removed before the party resumes work at the site.

5.5.4 After removal of a lockout/tagout device under the above conditions, the project manager shall forward a written record of the circumstances to the Regional Health and Safety Manager with a copy to the project files. A sample form that may be used for documentation is included in Appendix B.

6.0 ISOLATION PROCEDURES

6.1 Preparation

6.1.1 Review the system drawings to identify and locate all isolating devices that are required to be locked out to isolate the equipment.

6.1.2 Determine the accessories required to lockout the identified devices and acquire those accessories prior to going to the site.

6.1.3 At the site, survey the system paying particular attention to the following.

1) System physically agrees with the drawings previously reviewed.

2) Verify that procedures identified achieve isolation.

3) Verify that accessories on hand satisfy lockout/tagout requirements.

4) Locate isolating devices.

6.2 Stationary Electrically Driven Equipment

6.2.1 If the equipment is operating, turn it off using the controls. For automatically controlled pumps, this is commonly achieved by turning the Hand-Off-Auto (H-O-A) switch to the "Off" position.

6.2.2 Disconnect power to the equipment by turning the appropriate circuit breakers or safety disconnects to "Off". As each device is turned off, apply the lock and tag.

6.2.3 When the equipment has been isolated, operate the controls to confirm that the equipment has been de-energized. Do not check automatically controlled equipment by turning the controls to the "Auto" position, but by turning them to the "Hand" position. In "Auto" the equipment may not start only because the automatic controls are not calling for the motor to start.

6.2.4 When working in an electrical panel, a qualified person shall confirm the panel has been de-energized by using a voltmeter or other test device that detects the presence of voltage.

6.2.5 If the equipment is cord and plug connected, remove the plug from the receptacle after the equipment has been stopped.

6.2.6 To place equipment back in service, reverse the steps working from the equipment back to the last isolating device.

1) Insert plug into receptacle.

2) Close all disconnecting devices that were opened for isolation.

3) Test equipment by operating the controls in the manual and automatic modes.

6.3 Hydraulically and Pneumatically Operated Equipment

6.3.1 It is preferred that the entire hydraulic/pneumatic system be de-energized and isolated. If multiple pieces of equipment are being operated from a central hydraulic or pneumatic system and the other equipment must remain operational, then only the equipment to be worked on must be isolated.

6.3.2 Close the appropriate valves to isolate the equipment. Lockout and tag each valve as it is closed.

6.3.3 Relieve pressure in the hydraulic or pneumatic lines between the isolation valves and the equipment. Be aware of the operating pressure and temperature and the proper procedures for relieving pressure in the specific system.

6.3.4 Attempt to operate the equipment using the controls.

6.3.5 Check any pressure gauges on the equipment for residual pressure. If there is no pressure indicated, maintenance can begin.

6.3.6 To place the equipment back in service, once maintenance has been completed, perform the steps for isolation in reverse order.

6.4 Engine Driven Equipment

6.4.1 When work must be performed on equipment powered by an internal combustion engine or the engine itself, the engine must be rendered inoperable by one of the following means.

1) Disconnect the battery cables from the battery and insert a padlock and tag through the disconnected wire terminals.

2) Isolate the battery by means of a lockable battery disconnect switch. Lockout and tag the disconnect switch.

6.4.2 Attempt to start the engine to verify that isolation and lockout was achieved.

6.4.3 If the work to be performed is limited to the engine driven equipment and does not include the engine itself, the person performing the work may remove the ignition key and retain possession as long as the work is being performed. A tag shall be applied to the engine control panel.

This procedure is not acceptable when the work to be performed is on the engine itself.

7.0 ELECTRICAL WORK PRACTICES

7.1 General: The following safety-related work practices shall be employed to prevent electric shock or other injuries when work is performed on or near equipment or circuits which are or may be energized.

7.2 When an employee performs work on equipment where they may be exposed to live electrical circuits or equipment, the equipment or circuits shall be de-energized and locked and tagged out in accordance with 5.0 LOCKOUT/TAGOUT PROCEDURES.

7.3 Certain procedures such as troubleshooting and adjusting equipment cannot be performed with the equipment de-energized. This work shall be performed only by qualified personnel as designated by the Regional Engineering Manager.

EXHIBIT B

Project Site Lockout/Tagout Worksheet

Blank Project Site Worksheet

Filled Out Project Site Worksheet

DESIGN BASIS - LOCKOUT/TAGOUT WORKSHEET

Project: _____ Location: _____
Reviewed by: _____ Project No.: _____
Date: _____

	Yes	No	Date	Initials
General				
Existing System by others				
Code & Electrical Installation Review Performed	____	____	____	____
New/Designed Systems by GTI				
Panel dedicated to remediation system	____	____	____	____
Subcontractor to provide circuit breaker lockout equip.	____	____	____	____
As-built of system performed	____	____	____	____
Circuit verified and Noted on Panel Correctly	____	____	____	____
Separate power drop for Remediation System	____	____	____	____
Equipment				
Circuit Breaker Panel Lockable	____	____	____	____
Equipment Lockable: (1) Pumps: - WTDP	____	____	____	____*
- Transfer	____	____	____	____*
- Feed	____	____	____	____*
(2) Blowers	____	____	____	____*
(3) Compressors	____	____	____	____*
(4) Catalytic Units	____	____	____	____*
(5) Thermal Units	____	____	____	____*
(6) Other _____	____	____	____	____*
_____	____	____	____	____*
_____	____	____	____	____*
*For all "No" responses, see "In-line" disconnect section.				
Equipment in-line disconnects:				
(1) Pumps - WTDP	____	____	____	____
- Transfer	____	____	____	____
- Feed	____	____	____	____
(2) Blowers	____	____	____	____
(3) Compessor	____	____	____	____
(4) Catalytic	____	____	____	____
(5) Thermal	____	____	____	____
(6) Other _____	____	____	____	____
_____	____	____	____	____
_____	____	____	____	____
Accessories				
(Provide with lockable caps)				
Convenience Recepticles (GFCI)	____	____	____	____
Heater	____	____	____	____
Lights	____	____	____	____
Heat Tape	____	____	____	____
Monitoring Equipment	____	____	____	____
Small Control Equipment	____	____	____	____

_____ PM Sign-off*

_____ DEM/REM Sign-off*

*Prior to technician monitoring activities scheduled.

APPENDIX C-1: SITE-SPECIFIC LOCKOUT/TAGOUT PROCEDURES

APPENDIX C-1 SITE-SPECIFIC LOCKOUT/TAGOUT PROCEDURES		
Equipment	**Operation**	**Lockout Method/Location**

APPENDIX C-1: SITE-SPECIFIC LOCKOUT/TAGOUT PROCEDURES

APPENDIX C-1 SITE-SPECIFIC LOCKOUT/TAGOUT PROCEDURES		
Equipment	**Operation**	**Lockout Method/Location**
Blower A	Change fuse Change filter	Blower is hand wired to circuit breaker panel switch 7A. Use double pole red plastic breaker clip, lockout device, tag and red master lock. Check for stored energy prior to maintenance.
MW-1 = WTDP	Clean probe	Unplug at ENR receptacle at control panel in shed compound. Use plug cover for lockout with tag and a red master lock. Check for stored energy prior to maintenance.

EXHIBIT C

Lockout/Tagout Plan Elements

Required Implementation Tools

DRAFT

Lock Out/Tag Out Implementation
Plan Elements

The following steps need to be executed as part of the implementation process:

1. Tool Development (see list of implementation tools)
2. Communication of Implementation Plan
3. Training of System Inspectors
4. Inspection and Documentation of All Existing Sites
5. Training System Operators
6. Completion of Lock Out Worksheets for All Sites
7. Retrofitting any Systems Unable to be Satisfactorily Locked Out
8. Auditing System Operations for Compliance (both initial and on-going)
9. Integration of QC Procedures into Design and Installation

The following issues will be considered in planning for the implementation of each phase of the process listed above:

1. Specific Scope of Work and Measurement of Phase Completion
2. Estimated Cost
3. Distribution and Management of the Cost
4. Schedule
5. Designation of Corporate, Regional, and District Owners

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DRAFT

Lock Out/Tag Out Plan
Required Implementation Tools

1. Facility Lock Out Work Sheet - The worksheet will include spaces to specify lock out points referencing points on the design drawings and listing the equipment which is locked out by the particular point. The worksheet would also provide a space for listing any site specific lock out requirements.

2. Lock Removal Exception Worksheet - The worksheet will include spaces for the information required to report the removal of the lock by someone other than the original locker.

3. Lock Out Event Log - This log will be included in the site safety plan and will provide a record of the date of each lock out executed.

4. One-line Lock Out Point Template - The template will provide examples of lock out points they will be depicted on electrical one-line diagrams.

5. Lock Out Procedure - A simplified step by step lock out procedure.

6. Approved Lock Out Equipment List - This will specify GTI field proven devises to be used in locking out systems along with the manufacturer, the application, a recommended source, and a referenced equipment cut sheet.

7. System Inspector Training Plan - The training plan will provide the necessary information to the individuals who will actually inspect the existing sites and record the necessary information to develop a lock out plan. The target audience of the training plan will be the master technician level.

8. Inspection Documentation Package - The package will be used to document the existing systems during the system inspections. At a minimum, the package will include:

   A. System Evaluation Worksheet
   B. Inspection Instructions
   C. Examples of completed worksheets

8. System Operator and Maintainer Training Plan - The plan will incorporate hands-on training approaches for training the system operators on lock out. The OSHA 8 hour refresher may be the vehicle for this training.

EXHIBIT D

Lockout/Tagout Emergency Lock Removal Form

MEMORANDUM

TO: Distribution

FROM: _____

DATE: _____

SUBJECT: *Lockout/Tagout Device Removal*

Project Name: _____

Project Number: _____

==========

It was necessary to remove a lockout/tagout device by someone other than the person who applied the device due to their absence from the project site.

Lockout was applied by_____ Date:_____

☐ Verified absence of party named above on (date): _____ (name):_____

Remarks: _____

_____

☐ Efforts made to notify party named above on (date): _____ (name):_____

Remarks: _____

_____

☐ Party named above was notified on (date):_____ (name):_____

☐ Telephone ☐ Memo ☐ Personal contact

Remarks: _____

_____

☐ Lockout/Tagout device removed on (date): _____ (name):_____

cc: Regional Health and Safety Representative:_____

Project Manager:_____

DTC4:LOTODEV.FRM

GROUNDWATER TECHNOLOGY

EXHIBIT E

Examples of Marking and Tags and Hazards Signs for Lockout/Tagout

DRAFT

Lock Out/Tag Out Implementation
Plan Elements

The following steps need to be executed as part of the implementation process:

1. Tool Development (see list of implementation tools)
2. Communication of Implementation Plan
3. Training of System Inspectors
4. Inspection and Documentation of All Existing Sites
5. Training System Operators
6. Completion of Lock Out Worksheets for All Sites
7. Retrofitting any Systems Unable to be Satisfactorily Locked Out
8. Auditing System Operations for Compliance (both initial and on-going)
9. Integration of QC Procedures into Design and Installation

The following issues will be considered in planning for the implementation of each phase of the process listed above:

1. Specific Scope of Work and Measurement of Phase Completion
2. Estimated Cost
3. Distribution and Management of the Cost
4. Schedule
5. Designation of Corporate, Regional, and District Owners

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DRAFT

Lock Out/Tag Out Plan
Required Implementation Tools

1. Facility Lock Out Work Sheet - The worksheet will include spaces to specify lock out points referencing points on the design drawings and listing the equipment which is locked out by the particular point. The worksheet would also provide a space for listing any site specific lock out requirements.

2. Lock Removal Exception Worksheet - The worksheet will include spaces for the information required to report the removal of the lock by someone other than the original locker.

3. Lock Out Event Log - This log will be included in the site safety plan and will provide a record of the date of each lock out executed.

4. One-line Lock Out Point Template - The template will provide examples of lock out points they will be depicted on electrical one-line diagrams.

5. Lock Out Procedure - A simplified step by step lock out procedure.

6. Approved Lock Out Equipment List - This will specify GTI field proven devises to be used in locking out systems along with the manufacturer, the application, a recommended source, and a referenced equipment cut sheet.

7. System Inspector Training Plan - The training plan will provide the necessary information to the individuals who will actually inspect the existing sites and record the necessary information to develop a lock out plan. The target audience of the training plan will be the master technician level.

8. Inspection Documentation Package - The package will be used to document the existing systems during the system inspections. At a minimum, the package will include:

   A. System Evaluation Worksheet
   B. Inspection Instructions
   C. Examples of completed worksheets

8. System Operator and Maintainer Training Plan - The plan will incorporate hands-on training approaches for training the system operators on lock out. The OSHA 8 hour refresher may be the vehicle for this training.

EXHIBIT D

Lockout/Tagout Emergency Lock Removal Form

MEMORANDUM

TO: Distribution

FROM: _____

DATE: _____

SUBJECT: ***Lockout/Tagout Device Removal***

Project Name: _____

Project Number: _____

==========

It was necessary to remove a lockout/tagout device by someone other than the person who applied the device due to their absence from the project site.

Lockout was applied by_____ Date:_____

☐ Verified absence of party named above on (date): _____ (name):_____

Remarks: _____

_____

☐ Efforts made to notify party named above on (date): _____ (name):_____

Remarks: _____

_____

☐ Party named above was notified on (date):_____ (name):_____

☐ Telephone ☐ Memo ☐ Personal contact

Remarks: _____

_____

☐ Lockout/Tagout device removed on (date): _____ (name):_____

cc: Regional Health and Safety Representative:_____

Project Manager:_____

DTC4:LOTODEV.FRM

GROUNDWATER TECHNOLOGY

EXHIBIT E

Examples of Marking and Tags
and Hazards Signs for Lockout/Tagout

Over 120 Deaths and 60,000 Injuries Will Be Prevented By Lockouts This Year.

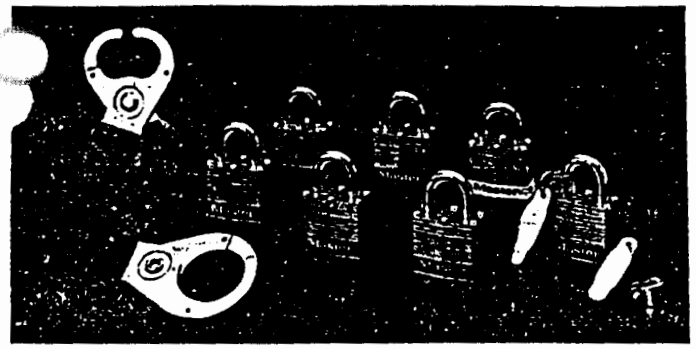
BRADY®

For a free copy of the Lockout/Tagout regulations, contact your local Signmark® Distributor:

BRADY: SIGNMARK DIV.
727 W. GLENDALE AVE.
P.O. BOX 571
MILWAUKEE, WI
5320
1-(800)-635-7557

'92 LOCKOUT/ TAGOUT PRODUCT LINE

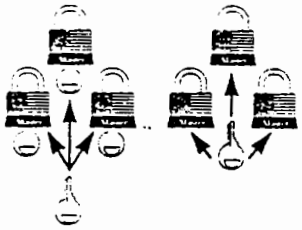
Locks and Accessories



Padlocks

High security Master padlock is ideal size for lockout. Rustproofed steel case; nickel plated shackle. Locks are 1-1/2" wide with 9/32" shackle diameter. Pair of brass keys included with each lock. Available with six different colored bumpers to provide easy visual identification by department (e.g. maintenance) or work team (e.g. electricians).
Standard Package: 6 locks

Bumper Color	Catalog No. 3/4" Shackle Clearance	Catalog No. 2" Shackle Clearance
Blue	65374	65528
Black	65382	65529
White	65383	65530
Red	65384	65531
Green	65385	65532
Yellow	65386	65533



Individual and master keyed

Keyed-alike

Custom Lock Options

Master locks are available with a variety of options to meet your company's needs. The most common lock options include:

- Master keying.
- Keyed alike locks.
- Variety of lock sizes and shackle lengths.
- Available in brass for harsh environments.

For more information call your local Signmark® distributor.

Safety Lockouts

Allows up to six workers to lockout a single energy source. Vinyl-coated high tensile steel. Plated to resist rust. Accepts six padlocks up to 3/8" shackle diameter. Available in two sizes.
Standard package: 12.
Catalog No. 65375
1" diameter jaws
Catalog No. 65376
1-1/2" diameter jaws

Lockout Starter Kit

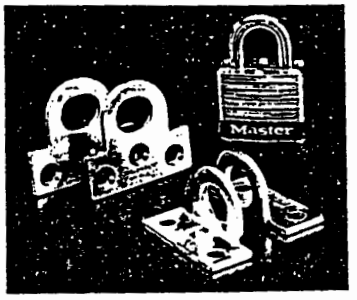
Includes two 1" safety lockouts, six 3/4" shackle padlocks (1 each of all six colors), six Brass I.D. tags and collar attachments.
Catalog No. 65380

Brass I.D. Tags

Allows instant identification of assigned padlock user. Designed to withstand rugged work environments. Tags can be personalized using commercial engravers or stamp kits.
Catalog No. 65378
12 brass tags and attachment rings
Catalog No. 65379
12 collars and rivets

Chain Attachments

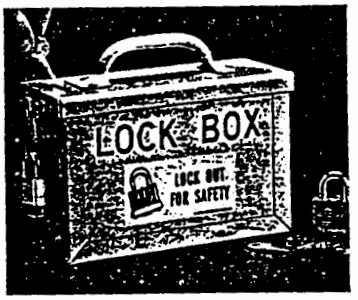
Optional 9" chain with pair of mounting s-hooks, for permanently attaching lockouts at pre-designated control and valve sites.
Catalog No. 65377
12 chain attachments



Padlock Eyes

OSHA requires that equipment be modified to accept locks and lockout devices. These padlock eyes can help bring you into compliance. Surface mounted eyes are made of 1/8" hard wrought steel.
Catalog No. 65686

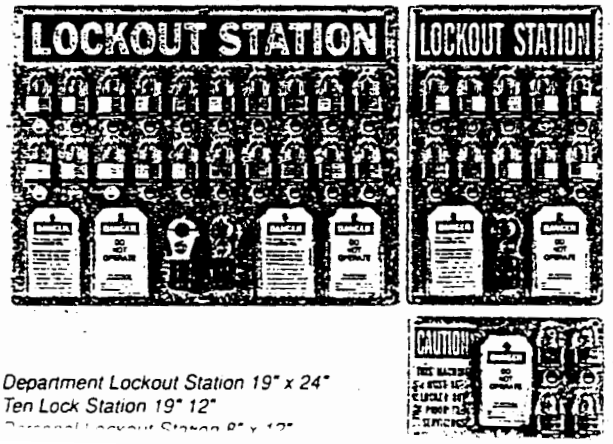
Tamper resistant inside mounting eyes – 2-1/2" wide, accepts shackle diameters up to 5/8".
Catalog No. 65687



Group Lock Box

For complex work team lockout situations. After machine or process is locked out, all keys are placed in lock box. Group leaders place lock on lock box until job is complete and all group members are cleared from work area. Heavy steel construction 10" x 4" x 6".
Catalog No. 65672

Lockout Stations



Department Lockout Station 19" x 24"
Ten Lock Station 19" 12"
Personal Lockout Station 8" x 12"

Brady's high visibility Lockout Stations make your locks, tags and lockouts easy to find and use. Built for the toughest conditions. Lockout stations are made of durable polycarbonate material.

Department Lockout Station

Catalog No. 65551
Station only.
Catalog No. 65552
Station with components.
Components include 20 blue bumper padlocks, 50 "Do Not Operate" tags (Cat. No. 65502) and 6-1" safety lockouts.

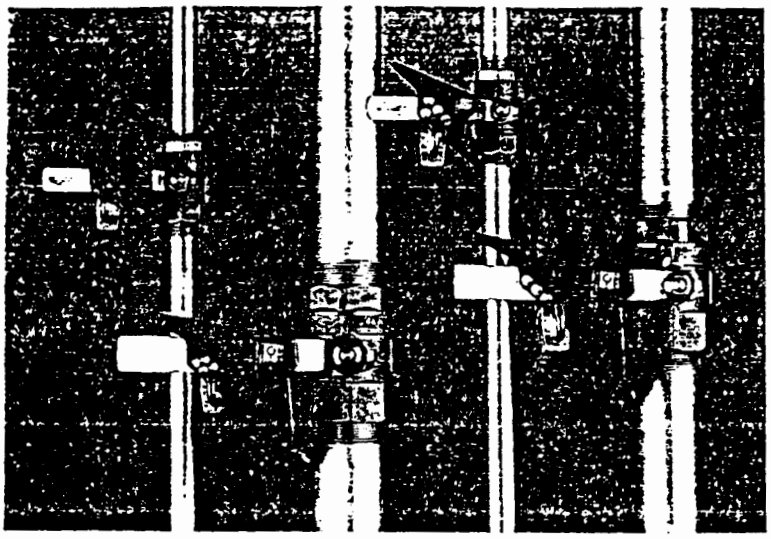
Ten Lock Station

Catalog No. 65679
Station only.
Catalog No. 65680
Station with components.
Components include 10 blue bumper padlocks, 25 "Do Not Operate" tags (Catalog No. 65502) and 3-1" Safety Lockouts.

Personal Lockout Station

Catalog No. 65550
Station only.
Catalog No. 65553
Station with components.
Components include 4 blue bumper padlocks and 25 "Do Not Operate" tags (Catalog No. 65502).

Ball Valve Lockout Devices



Brady Ball Valve Lockout Devices come in two sizes to lock out 1/4" to 1" and 1-1/4" to 3" ball valves.

Ball Valve Lockout Devices

Best available method for locking out ball valves.*

- Patented design fits all major brand ball valves.
- Two new models accept 3/8" shackle padlocks.
- Simple design makes it easy to use.
- Complies with OSHA's lockout standard.

Chain Attachment. Keep lockout device near valves that are locked out frequently. Standard package: 5 chain attachment assemblies.

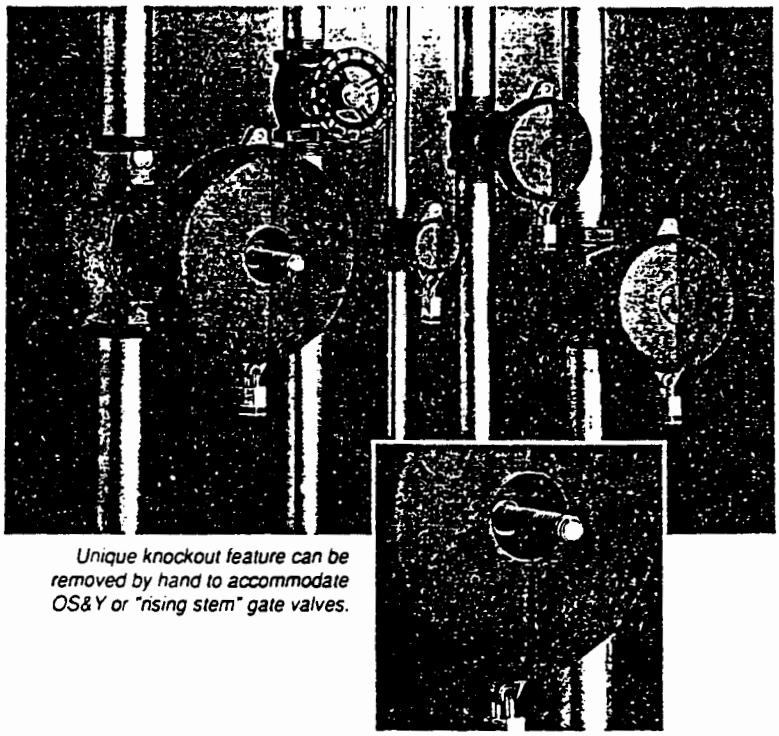
Catalog No. 65668

Valve Size	Padlock Shackle max. diameter	Padlock Shackle min. length	Material	Cat. No.
1/4" to 1"	9/32"	1"	Super Tough Nylon™	65666
1/4" to 1"	3/8"	3/4"	Heavy Steel	65692
1-1/4" to 3"	9/32"	3/4"	Heavy Steel	65669
1-1/4" to 3"	3/8"	3/4"	Heavy Steel	65693

Patent No. 5,003,797

*65666 requires lock with 1" shackle clearance.

Gate Valve Lockouts



Unique knockout feature can be removed by hand to accommodate OS&Y or "rising stem" gate valves.

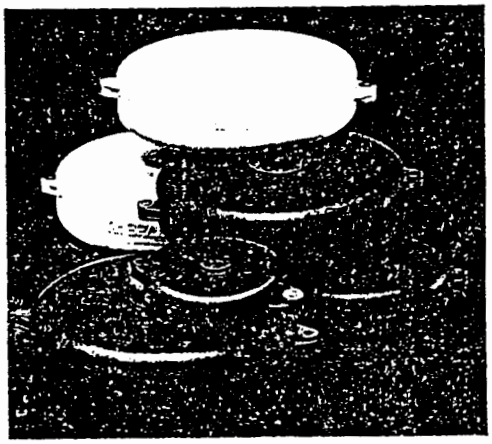
Gate Valve Lockouts

Make locking out valves safe and easy with the new Brady Gate Valve Lockouts. Available in four sizes to fit valve handles from 1" to 10" in diameter. Made of durable, non-adherent plastic to resist chemicals and hot and cold temperatures.

- New stainless steel hinge design for added strength and security.
- Now available in red, blue, green, and yellow for added versatility.
- Unique knockout feature accommodates OS&Y or "rising stem" gate valves.
- Designed to accept all locks with up to 3/8" shackle diameter and 3/4" or greater vertical shackle clearance.

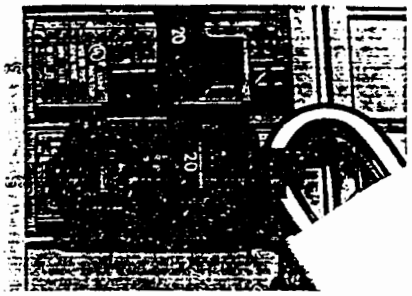
Patent Applied For

Valve Handle Size	Catalog Number			
	Red	Yellow	Green	Blue
1" to 2-1/2"	65560	65590	65595	65585
2-1/2" to 5"	65561	65591	65596	65586
5" to 6-1/2"	65562	65592	65597	65587
6-1/2" to 10"	65563	65593	65598	65588
10" to 13"	65564	65594	65599	65589



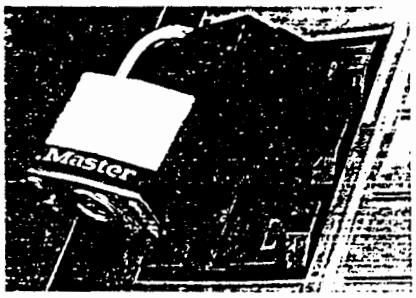
Now available in four colors. Use red and green devices to indicate if valve is locked in open (green) or closed (red) position or use green (non-hazardous gas), blue (non-hazardous liquid), and yellow (hazardous gas or liquid) lockout devices to correspond with ANSI A13.1 pipe color code scheme.

Circuit Breaker Lockouts



Single Pole Breaker Lockout

Device locks out most major brand breaker switches. Simple design snaps onto breaker switch and accepts up to 9/32" shackle diameter lock or nylon tie.
Standard package: 6 devices
Catalog No. 65688

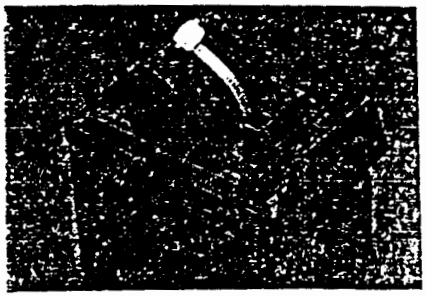


Multi Pole Breaker Lockout

Locks out most major brand 2 and 3 pole breaker switches (General Electric, I-T-E, Sylvania, Challenger, Bryant and Westinghouse). Standard package: 6 devices.
Catalog No. 65694

Cutler Hammer 2/3 pole breaker lockout. Standard package: 6 devices.
Catalog No. 65698

Square D (2/3 pole) breakers use **Catalog No. 65688** in conjunction with the Square D Adaptor kit. **Catalog No. 65697**

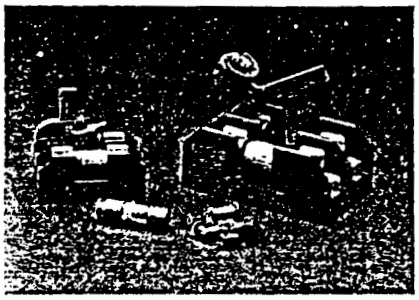


Multi Pole Breaker Blockout

Designed for all major multi pole breakers including Cutler-Hammer, General Switch Co. and Westinghouse Quicklag style breakers not covered by the Multi pole breaker device. Blockout snaps onto breaker switch and secures the switch in the off position with self-locking nylon tie. Standard package: 6 devices
Catalog No. 65689

6" self-locking nylon ties.
Standard package: 10 ties.
Catalog No. 91165

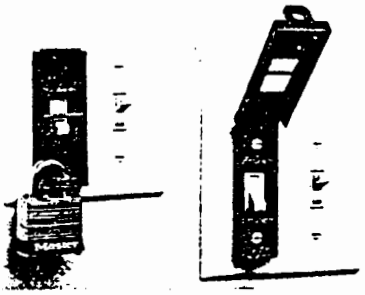
Electrical Lockout Devices



Fuse Lockout Devices

Lockout 13/32" and 9/16" fuses with Brady's new Fuse Lockout Devices. Fits most Buss and Gould fuse blocks. For tagout applications use Brady's Fuse Blockout Devices.

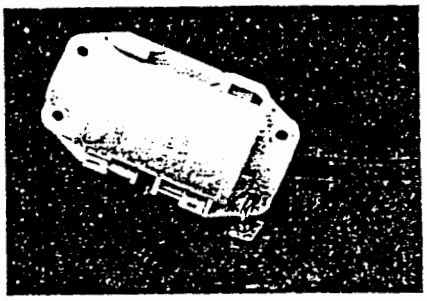
Standard package: 6 devices.
Catalog No. 65750 13/32" Fuse Lockout
Catalog No. 65751 9/16" Fuse Lockout
Catalog No. 65690 1/4", 9/32", 13/32" and 9/16" Fuse Blockout
Catalog No. 65691 13/16", 1-1/16" and Blade Fuse Blockout



Wall Switch Lockout

Easy to install device can be used with most wall mounted switches. Can be used to lock switch in either on or off position. Install using existing screws.

Standard package: 6 devices.
Catalog No. 65696

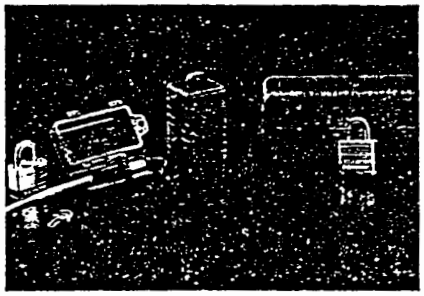


Hubbell Plugout

Hubbell Plugout™ designed to lock out most 220 volt plugs.

- Can be stored on cord/cable when not in use.
- 2 step close and slide assembly for added security.
- Made of high impact U.V. polymer for extra strength.
- Accepts up to 4 locks with up to 3/8" shackle diameter.

Standard package: 1 device.
Catalog No. 65695

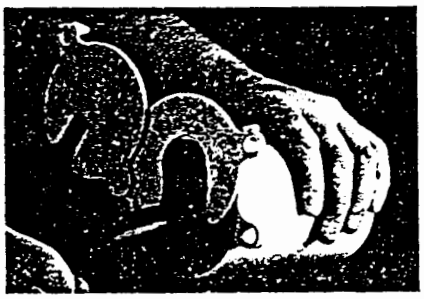


Lock A Plug

Designed for heavy duty applications. Lock A Plug is available in sizes to fit 110, 220 and 550 volt plugs. Made of polypropylene.

110 volt device: 2" x 2" x 3.5"
220/550 volt devices: 3.25" x 3.25" x 7"

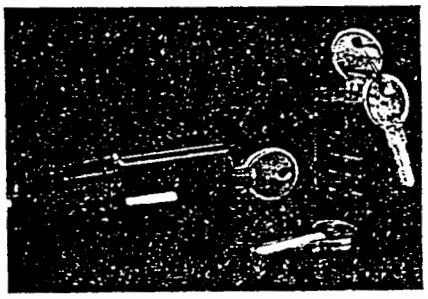
Catalog No.	Description
65674	110 volt
65675	220/550 volt



Plug Lock

Safe and effective method for locking out electrical plugs. This new lockout device (6" tall, 3.25" diameter) adjusts to lock out a variety of plug sizes. Made of durable plastic material. Accepts standard locks up to 3/8" shackle diameter.

Standard package: 1.
Catalog No. 65566



Plug Hugger™

Ideal for office and frequently locked out cords. Plug Hugger™ slides over cord prongs and locks. Cord can not be plugged in with Plug Hugger™ in place. Plug Hugger™ can not be removed without a key.

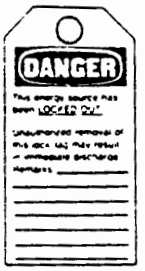
Catalog No. 65673

Rev. Side #1 - 65502
Rev. Side #2 - 65535
Rev. Side #3 - 65670

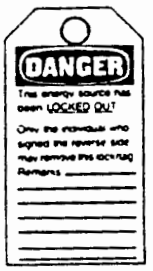
Rev. Side #1 - 65503
Rev. Side #2 - 65521

Rev. Side #1 - 65504
Rev. Side #2 - 65522

Rev. Side #1 - 65505
Rev. Side #2 - 65523



Reverse Side #1



Reverse Side #2

Reverse Side #3

Rev. Side #1 - 65506
Rev. Side #2 - 65534

Rev. Side #1 - 65515
Rev. Side #2 - 65524

Rev. Side #1 - 65520
Rev. Side #2 - 65525
Rev. Side #3 - 65671

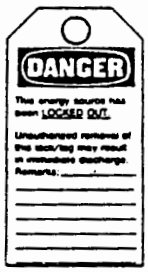
Rev. Side #1 - 65526
Rev. Side #2 - 65527

OSHA requires that all lockout and tagout devices shall indicate the identity of the employee applying the device. Tags are designed for repeated use. Simply assign a set of tags to each employee.

- Brass Grommet for added strength. Large enough to accept most locks (7/16" inside diameter).
- Polyester laminate protects graphics, wipes clean and stands up against water, grease and extreme temperatures.
- Write-on matte finish allows workers to personalize tags with pen, pencil or marker.
- Heavy duty construction prevents accidental removal. Withstands over 80 lbs. of pulling pressure.
- 8" Nylon ties – 50 lbs. unlocking strength (Cat. No. 91166) and permanent Markers (Cat. No. 87052) available for attaching and signing tags.
- Standard Package: 25 identical 5-1/2" x 3" tags.
- Custom tags available, call your local distributor for more information.

Photo Identification Tags

Catalog No. 65500



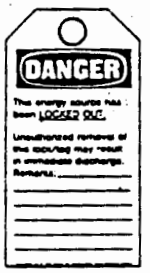
Reverse Side

Standard Package:
25 – 5-1/4" x 2-3/4" paper tags.
25 – 5-1/2" x 3" overlaminate pouches.
Catalog No. 65500

Heavy Duty Laminated Tags

Photo Identification tags make it easy to identify individuals working on equipment. Photographs can be taken with most photo I.D. cameras. These tags provide long lasting protection. To use, simply sign tag, place photo in designated area, insert tag into overlaminate pouch and run through heat laminator (Catalog No. 23320). Tag has chamfered corners and 7/16" hole.

Catalog No. 65501



Reverse Side

Standard Package:
25 identical 5-3/4" x 3" tags.
Catalog No. 65501

Self Sealing Laminated Tags

Make it easy to identify individuals working on equipment. These tags are rigid vinyl with polyester overlaminate. To use, employee signs tag, places photo on tag and applies self-sticking laminate to front of tag. Tag has chamfered corners and heavy-duty 7/16" brass grommet.

DANGER

HIGH VOLTAGE

AUTHORIZED PERSONNEL ONLY

OS4-331-G © EMED Co., Inc. • 1-800-442-3633

CAUTION

OSHA-NEC REGULATIONS

AREA IN FRONT OF THIS ELECTRICAL PANEL MUST BE KEPT CLEAR FOR 36 INCHES

OS4-316-G ©EMED Co., Bflo., NY 14240 • 1-800-442-3633

LOCK-
OUT
POINT

AQS2 ©EMED Co., Bflo., NY 14240

LOCK OUT FOR
SAFETY

Shortcuts
Cause Accidents

QS3212 © EMED Co., Inc. • 1-800-442-3633

LOCK-
OUT
POINT

SQS15 C[illegible] 1-800-442-3633

DANGER

HIGH VOLTAGE
DO NOT ENTER

TAKE THE TIME

TO LOCK IT OUT!

SAFETY LASTS A LIFETIME

42551 © EMED Co., Inc. • 1-800-442-3833

NOTICE

USE LOCKOUT

DURING MAINTENANCE OR ANY OPERATOR ADJUSTMENT

40406 © Emed Co., Bflo., N.Y. 14240

EXHIBIT F

Sample Policy & Procedure Notice

MEMORANDUM

To: Regional Managers
District Managers

From: Michael Sullivan
Robert N. Higgins

cc. Walt Barber
Zenaido Quintana

Subject: Lockout/Tagout Procedure

Date: September 15, 1992

DRAFT

When maintaining equipment where the potential for electrical shock or where explosion-proof protection of the equipment may be compromised, the system components must be appropriately isolated, locked-out/tagged-out, in conformance with Groundwater's Lockout/Tagout procedure originally issued on February 11, 1991.

All equipment &/or systems, which will be maintained by Groundwater Technology, must be installed/retrofitted or be provided with appropriate lockable disconnect devices to isolate the equipment from the energy source. Isolation points will be indicated on the one-line electrical diagram or the P&ID for the system and approved by the individual(s) designated by the operations managers.

Isolation from energy sources may include the following considerations:

- Lockable In-line Equipment Disconnects
- Lockable Main-line Disconnect Panel
- Lockable Circuit Breaker Panel.
- Lockable Plug Caps for Small Equipment (e.g. Heaters, Heat Tape, etc.)

Design basis worksheets, system site inspection checklists and examples of P&ID/Electrical One-Line design drawings are available from the Corporate Technical Services group.

If you have any questions or require technical input, please contact Michael Sullivan or Robert N. Higgins at 1-617-769-7600.

September 18, 1992

LOCKOUT/TAGOUT POLICY

OSHA guidelines presented under 29 CFR 1910, outline standard practices necessary to disable machinery or equipment and to prevent the release of potentially hazardous energy while maintenance and/or servicing activities are being performed.

When maintaining equipment where the potential for electrical shock or where explosion-proof protection of the equipment may be compromised, the system components must be appropriately isolated, locked-out/tagged-out, in conformance with OSHA's requirements and Groundwater's Lockout/Tagout procedure originally issued on February 11, 1991.

All equipment &/or systems, which will be maintained by Groundwater Technology, must be installed/retrofitted or be provided with appropriate lockable disconnect devices to isolate the equipment from the energy source. Isolation points will be indicated on the one-line electrical diagram or the P&ID for the system and approved by the individual(s) designated by the operations managers.

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Design basis worksheets, system site inspection checklists and examples of P&ID/Electrical One-Line design drawings are available from the Corporate Technical Services group.

If you have any questions or require technical input, please contact the Technical Services Group at (617)-769-7600.

EXHIBIT G

Possible Locations for Lockout/Tagout

Lockout/Tagout required when there is potential for serious personal injury:

Electricity Hazard

Machinery Hazard

Liquid Hazard

Dust Hazard

Hydraulics Hazard

Pneumatics Hazard

Gases Hazard

Elevator Shaft Hazard

Compactor Hazard

Pugmill Hazard

APPENDIX C-3

SPILL PROCEDURES

COMPLIANCE PROCEDURE FOR REPORTING SPILLS AND RELEASES

COMPLIANCE PROCEDURE

This procedure applies to all Enserch Environmental Corporation (EEC) employees who learn of the existence of a spill or release during the course of a remediation project. It describes four categories of spills which EEC employees must report, and identifies the specific reporting process to follow for each category. The procedure is to be implemented immediately once an EEC employee learns of the existence of a spill or release, regardless of who may have caused the spill or when the spill may have occurred.

This procedure is a two step process: first, evaluation of all spills and releases; second, reporting of spills which fit any one of four categories. These procedures shall be presented to the Client by the Project Manager prior to beginning the project. Any Client questions or concerns shall be referred to the Compliance Manager with jurisdiction over the project.

Evaluation of All Spills/Releases

The following evaluation must be completed on an immediate basis for all spills/releases. This evaluation will determine if the spill/release must be reported by EEC employees.

Question 1) Is the Spill/Release an "EEC Spill/Release"?

For purposes of this procedure a spill/release is considered an "EEC spill/release" under any one of the following circumstances:

- The spill/release is physically caused by, or is suspected to have been caused by an EEC or EEC subcontractor employee; or
- The spill/release is from, or is suspected to have been from, a facility or equipment which is:
  - owned by EEC or an EEC subcontractor; or
  - operated by EEC or an EEC subcontractor; or
  - under EEC's direct or indirect control as a construction manager, oversight contractor, or similar capacity.

All other spills/releases are considered "client spills/releases" for purposes of this procedure.

Question 2) Is the Spill/Release Subject to Any Federal, State or Local Spill/Release Reporting Requirements?

This question is answered by reviewing the spill/release reporting information set forth in the Attachment B. This section presents information on the chemical substances and reportable quantities specified by applicable regulations. Agency contacts and information required at the time of reporting is also set forth.

If yes, go to "Reporting Procedure For Spills/Releases."

If no, go to Question 3.

Question 3) Does The Spill/Release Present a Hazard To Human Health?

For purposes of this procedure a spill/release is considered to present a hazard to human health under any one of the following circumstances:

- The spill/release results in groundwater contamination which has entered, or is about to enter, known drinking water sources (wells or surface water bodies); or
- The spill/release has caused, or is about to cause, contamination of surface soils or other materials in areas accessible to the general public; or
- The spill/release has caused, or is about to cause, odors/air contamination detectable in areas accessible to the general public.

If an EEC employee is uncertain of the presence of a "hazard", the Eastern or Western Regulatory Compliance Manager may be contacted to discuss the circumstances of the spill/release.

Reporting Procedure For Spills/Releases

Spills/releases which fit any one of the following four categories must be reported as specified. Spills/releases which do not fit one of these categories need not be reported.

Category 1) An EEC Spill/Release, or Suspected Release, Which Is Subject To A Federal/State/Local Spill/Release Requirement (Yes to Questions 1 and 2)

EEC policy is that spills/releases which fit this category must be immediately reported to the regulatory agencies as specified in Attachment B. The Compliance Manager with jurisdiction over the project shall be notified after the spill has been reported to the agencies.

Category 2) An EEC Spill/Release, or Suspected Release, Which Is Not Subject To A Federal/State/Local/Spill/Release ReportingRequirement, But Presents a Hazard to Human Health (Yes to Questions 1 and 3, No to Question 2)

EEC policy is that spills/releases which fit this category shall be immediately reported to the Eastern or Western Regulatory Compliance Manager, who will provide further direction on EEC's response to such spills. If an EEC employee is uncertain of the presence of a "hazard", the Compliance Manager may be contacted to discuss the circumstances of the spill/release.

Category 3) A Client Spill/Release, Which Is Subject To A Federal/State/Local Spill/Release Reporting Requirement (No to Question 1, Yes to Question 2)

EEC policy is that spills/releases which fit this category shall be reported by EEC or the client. The reporting procedure followed depends upon whether the spill/release is a "real time" or a "historic" event.

If the spill/release is a "real time" event (EEC personnel observe the occurrence of the spill/release or learn of it immediately after it happens), the EEC Project Manager shall immediately contact the client, to give the client a "right of first refusal" to report the spill/release. EEC shall also contact the appropriate operations Vice President and the Compliance Manager with jurisdiction over the project. If the client cannot be reached or declines to report, the EEC Project Manager shall immediately report the spill/release to the agencies identified in Attachment B.

If the spill/release is a "historic" event (EEC personnel observe or learn of evidence that a spill/release has occurred in the past), the EEC Compliance Manager with jurisdiction over the project shall be notified immediately.

Category 4) A Client Spill/Release, Which Is Not Subject To A Federal/State/Local Spill/Release Reporting Requirement, But Presents a Hazard to Human Health (No to Questions 1 and 2, Yes to Question 3)

EEC policy is that spills/releases which fit this category shall be immediately reported to the Eastern or Western Regulatory Compliance Manager, who will provide further direction on EEC's response to such spills. If an EEC employee is uncertain of the presence of a "hazard", the Compliance Manager may be contacted to discuss the circumstances of the spill/release.

OPERATIONAL ISSUES

During day to day operations employees of environmental service organizations learn of the existence of spills and releases. The circumstances of spills and releases must be immediately evaluated to determine if EEC has an obligation to report the spill or take other response action. All EEC employees must follow this spill/release reporting procedure so that EEC can proceed in accordance with the Federal, State, or local requirements which apply to certain spills.

An EEC response dictated by this procedure may raise concerns regarding, for example, client-imposed spill reporting procedures or confidentiality provisions in EEC's contract with the client. Such concerns shall not delay an EEC response dictated by this procedure. EEC employees who become aware of such concerns, either before or after a spill/release occurs, shall refer them to the Compliance Manager with jurisdiction over the project.

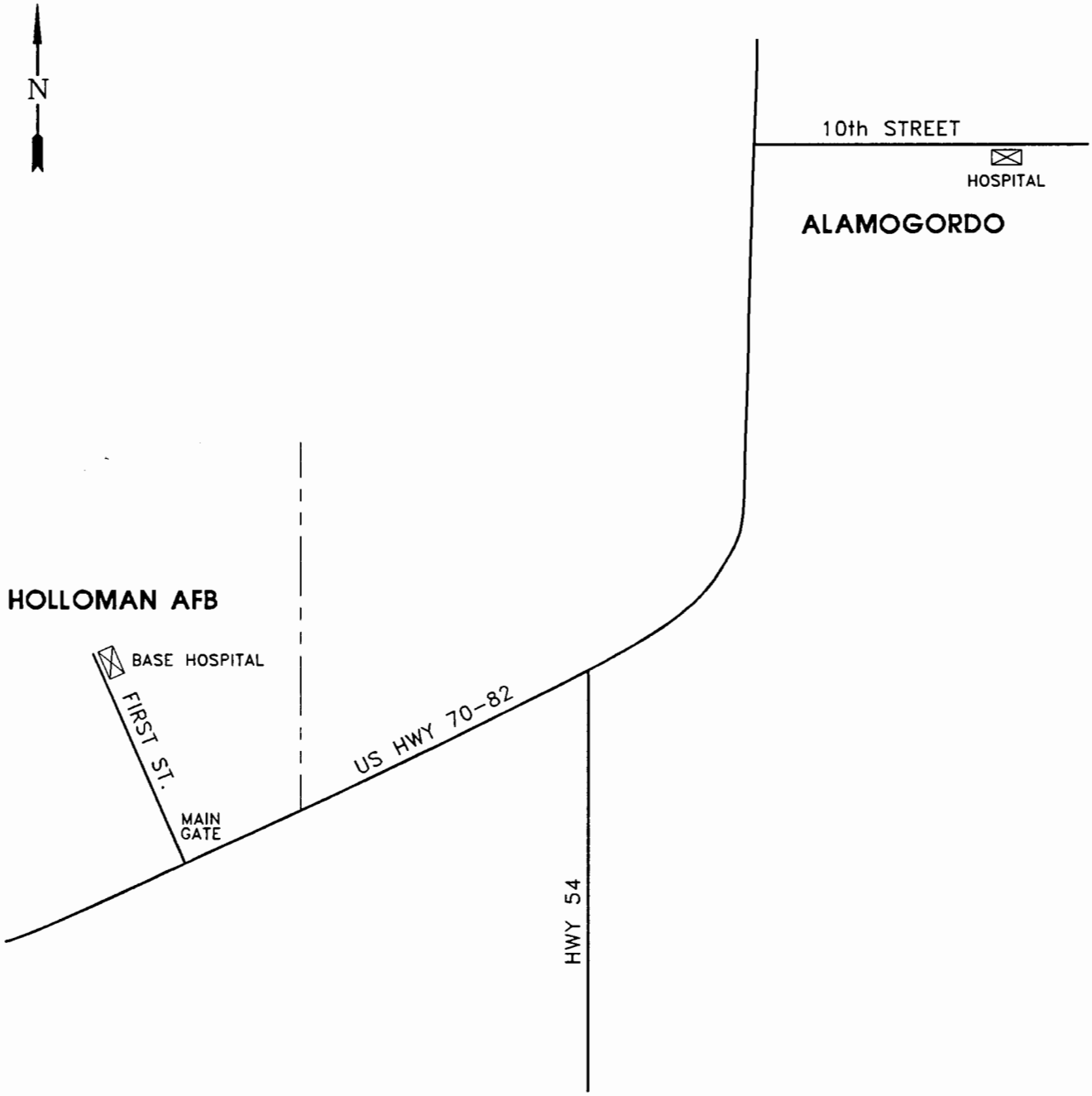
REGULATORY ISSUES

Numerous Federal, State and local regulatory requirements govern spill/release reporting and response activities. EEC therefore has developed this procedure to evaluate employee information on spills and releases and provide for necessary reporting and other response action. Depending upon the circumstances, reporting may be necessary under both Federal (Clean Water Act, CERCLA, SARA Title III, RCRA, TSCA) and state or local spill reporting programs. Some programs specify minimum quantities, others do not. Some programs apply to virtually any spill, others are very specific.

Outside contractor employees have been indicted and convicted of criminal violations of Federal spill/release reporting requirements. This obligation may hold even though the spill is the client's and not the contractor's. In the absence of such requirements, money damages may still be imposed by a court for failure to disclose knowledge of spills which present a hazard to human health. For these reasons it is essential that all EEC employees follow this procedure as soon as they learn of the existence of a spill or release.

APPENDIX D

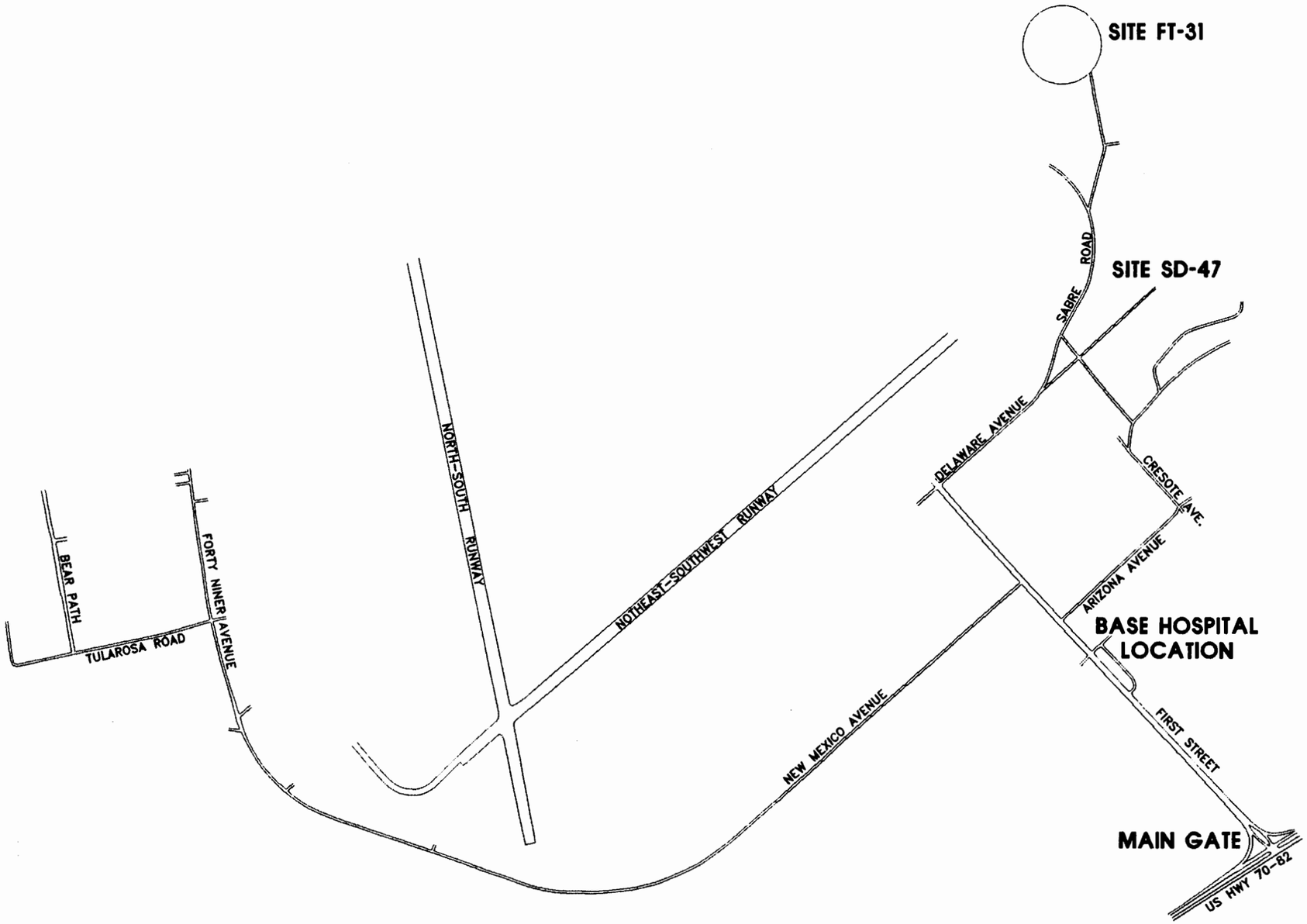
MAPS AND FIGURES



NOT TO SCALE

HOSPITAL LOCATION MAP

CLIENT: HOLLOMAN AIR FORCE BASE	FILE: 2201-SL (1:1)		PROJECT NO.: 83001-2201	PM / PE/RG
	REV.			
LOCATION: ALAMOGORDO, NEW MEXICO	DES. KG	DET. AJK	DATE: 12/9/94	FIGURE: 1



0 FEET 1,500
SCALE

GENERAL SITE PLAN

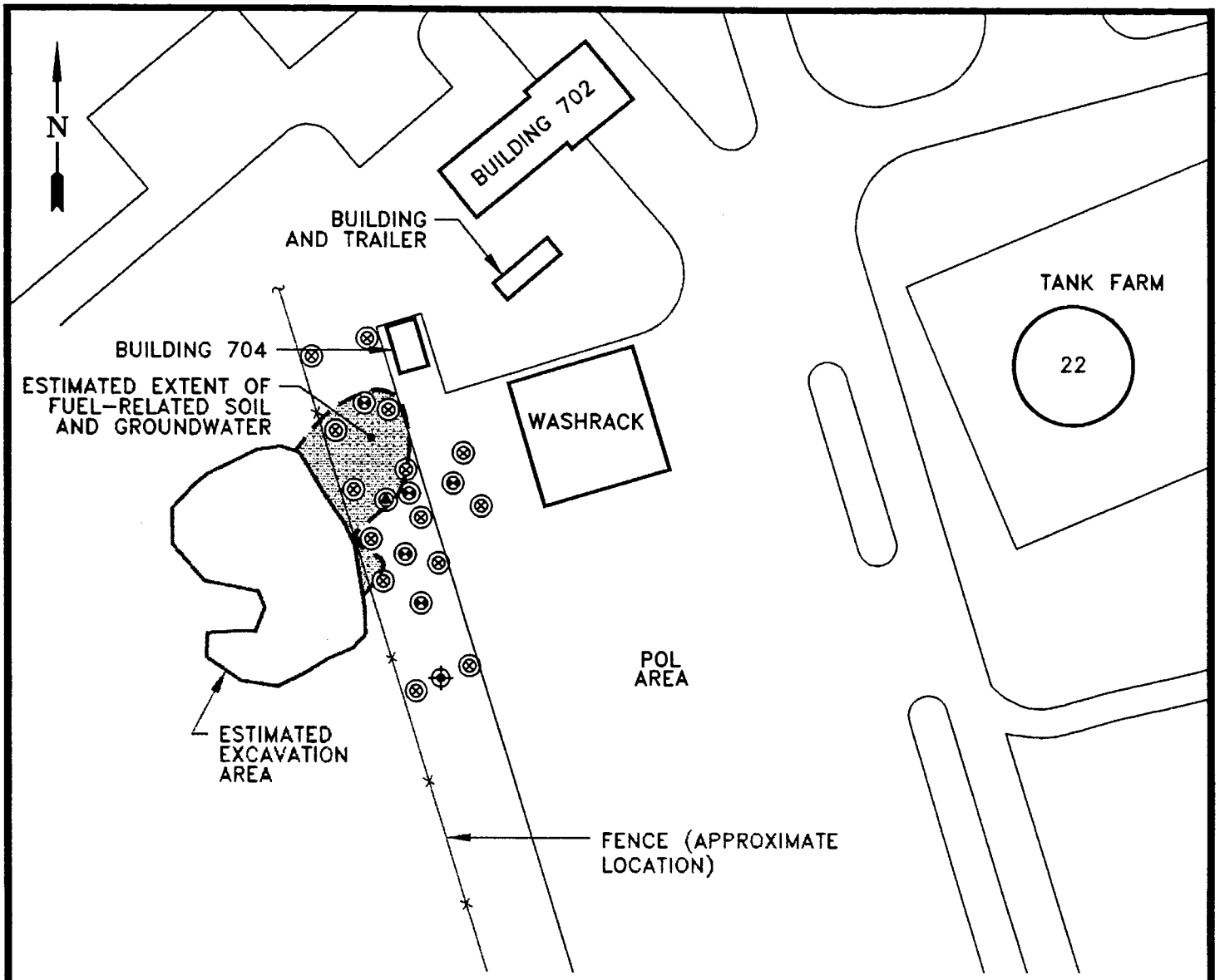
CLIENT:
HOLLOMAN AIR FORCE BASE
ALAMOGORDO, NEW MEXICO

LOCATION:
HOLLOMAN AFB
ALAMOGORDO, NEW MEXICO

FILE:	PROJECT NO.:
2201SMBA (1:1500)	83001-2201

REV.:

DES.:	DET.:	DATE:	FIGURE:
KG	AJK	12/9/94	2
PM:		PE/RG:	

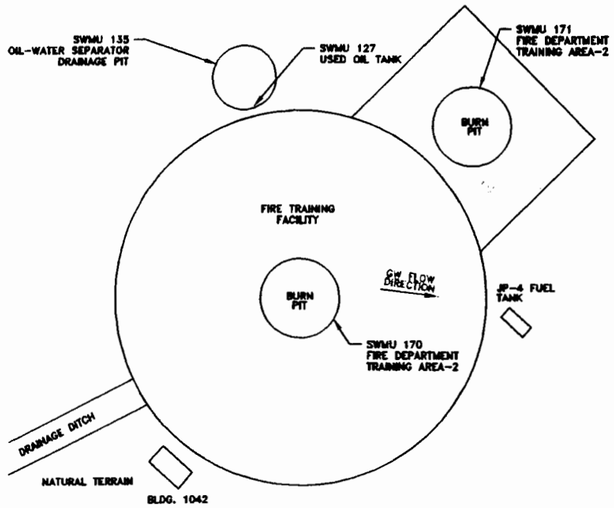


LEGEND

- PROPOSED SOIL GAS SURVEY LOCATIONS
- PROPOSED BACKGROUND MONITORING WELL LOCATION
- PROPOSED INJECTION WELL LOCATION
- PROPOSED MONITORING POINT LOCATIONS

NOTE:
1. FINAL WELL LOCATIONS WILL BE DETERMINED FROM THE SOIL GAS SURVEY DATA.

PROJECT: BIOVENTING INITIATIVE WAD NO. 7	0 FEET 100 SCALE	**PROPOSED SAMPLE/WELL LOCATIONS**			
CLIENT: HOLLOMAN AIR FORCE BASE ALAMOGORDO, NEW MEXICO	FILE: SD-47SM1 (1:100)		PROJECT NO.: 83001-2201	PM	PE/RG
	REV.				
LOCATION: SITE SD-47 POL WASHRACK DISCHARGE AREA	DES. KG	DET. AJK	DATE: 12/15/94	FIGURE: **2-1**	

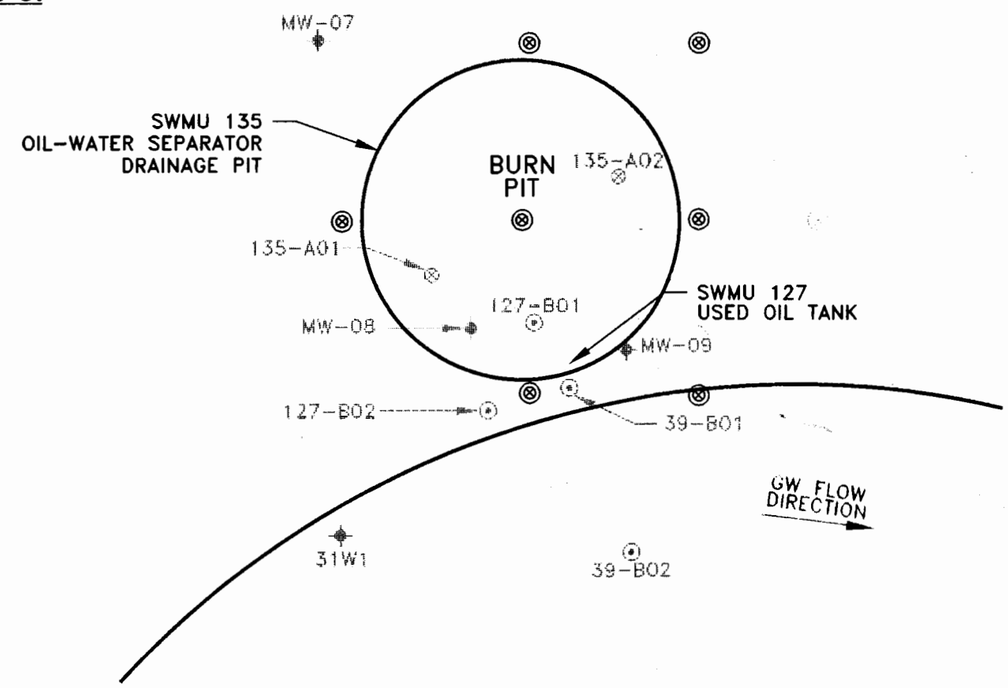


OVERALL SITE PLAN - FT-31

LEGEND

- MONITORING WELL LOCATIONS
- SOIL BORING LOCATIONS
- SOIL SAMPLE LOCATIONS
- PROPOSED SOIL GAS SURVEY LOCATIONS

NOTE:
1. SITE LOCATIONS ARE APPROXIMATE.
2. FINAL WELL LOCATIONS WILL BE DETERMINED FROM THE SOIL GAS SURVEY DATA.



NORTHERN AREA DETAIL - FT-31

PROJECT: BIOVENTING INITIATIVE		0 FEET 40 SCALE	
PROPOSED SAMPLE LOCATIONS			
CLIENT: HOLLOMAN AIR FORCE BASE ALAMOGORDO, NEW MEXICO			
LOCATION: SITE FT-31 FIRE DEPARTMENT TRAINING FACILITY			
FILE: FT-31SM (1:40)		PROJECT NO.: 83001-2201	
REV.:			
DES.: KG	DET.: AJK	DATE: 12/15/94	FIGURE: 2-2
PM:		PE/RG:	